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THESIS

FIELD-DEPLOYABLE VIDEO CLOUD SOLUTION

by

Jonathan R. Stephens
Robert C. Adams

March 2016

Thesis Advisor:	Gurminder Singh
Second Reader:	Brian Steckler

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13. ABSTRACT (maximum 200 words)

Digital video has become a ubiquitous communications tool. In recent years, great advances have been made in the capture and display of ultra-high definition (UHD) video. Delivering UHD video over networks, however, requires a high-throughput connection that is not always present, especially in wireless networks. The U.S. Navy has established a need for video services that can distribute high-quality video from within the fleet to anywhere in the world at a moment's notice. This requires a high-throughput satellite communications system that links ship-based assets with each other, as well as with land-based assets.

This thesis evaluates a satellite communications solution that can be used to deliver UHD video to customers during at-sea periods for a wide variety of use cases and applications. A mobile video content management server was evaluated and then coupled with a high-throughput satellite communications solution to meet public affairs digital video content demands.

Our evaluation of the O3b Network's transportable tracking fly away antenna system reveals that it can adequately handle the network demand of UHD video content transmission.

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FIELD-DEPLOYABLE VIDEO CLOUD SOLUTION

Jonathan R. Stephens
Lieutenant Commander, United States Navy
B.S., Wayland Baptist University, 2003

Robert C. Adams
Lieutenant, United States Navy
B.S., University of Kansas, 2008

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March 2016

Approved by: Gurminder Singh, Ph.D.
Thesis Advisor

Brian Steckler
Second Reader

Dan Boger, Ph.D.
Chair, Department of Information Sciences

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

3G-SDI	3 gigabit–serial data interface
10GE	10 Gigabit ethernet
ACES	Academy of Motion Picture Arts and Sciences
AEHF	advanced extremely high frequency
API	application program interface
ASIC	application specific integrated circuit
ATO	air tasking order
AVC	advanced video coding
Bps	bits per second
BSD	Berkeley software distribution
BOM	bill of materials
CENTCOM	The United States Central Command
CNAL	Commander Naval Force Atlantic
CODEC	coder/decoder
COMREL	community relation
COTS	commercial off the shelf
DOD	Department of Defense
DOCSIS	data over cable system interface specification
DSL	digital subscriber link
DSLR	digital single-lens reflex
DSCA	Defense Security Cooperation Agency
DSCS	defense satellite communications system
DVIDS	Defense Video and Imagery Distribution System
DVD	digital versatile disc
EMI	electromagnetic interference

FEC	forward error correction
Fps	frames per second
Gbps	gigabits per second
GEO	geostationary earth orbit
GHz	Giga-hertz
GLIF	Global Lambda Integrated Facility
GUI	graphical user interface
HAIPE	High Assurance Internet Protocol Encryption
HD	high-definition
HD-SDI	high-definition serial data interface
HDD	hard disk drive
HDTV	high-definition television
HEVC	highly efficient video coding
IATA	International Transportation Association
IDS	intrusion detection system
IPS	intrusion prevention system
ITU	International Telecommunications Union
IP	Internet Protocol
Kbps	kilo-bits per second
LAN	local area network
LED	light emitting diode
Li-ion	lithium ion
LTE	long term evolution
Mbps	mega-bits per second
MBps	mega-bytes per second

MEO	medium earth orbit
MCTSSA	Marine Corps Tactical Systems Support Activity
MILSATCOM	military satellite communications
MILSTAR	military strategic and tactical relay
MMT	MPEG modern transport
MPEG	Moving Picture Experts Group
MUOS	mobile user objective system
NAL	network abstraction layer
NATO	North Atlantic Treaty Organization
NIC	network interface card
NiMH	nickel metal hydride
NLE	non-linear editing
NPS	Naval Postgraduate School
NSN	national stock number
O3b	Other Three Billion
ONR	Office of Naval Research
PAO	Public Affairs Officer
QoS	quality of service
SATCOM	satellite communications
SD	standard definition
SDI	serial data interface
SMPTE	Society of Motion Picture and Television Engineers
SNG	satellite news gathering
SPC	soldier portable charger
SSD	solid state drive
SVS	shipboard video server

TCP	transmission control protocol
TFAAS	tracking fly away antenna system
UFO	ultra-high frequency follow-on
UHD	ultra-high definition
UHDTV	ultra-high definition television
UHF	ultra-high frequency
USB	universal serial bus
VAC	volts alternating current
VAM	video acquisition module
VOIP	voice over Internet protocol
VCL	video coding layer
VDC	volts direct current
VPN	virtual private network
WGS	wideband global satcom

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I. INTRODUCTION

Digital video has become a ubiquitous communication tool for business and government entities, facilitating everything from valuable public relations articulation to virtual think tanks and collaboration. The U.S. Navy has established a need for expanded video services that allow for the distribution of high-quality video from within the fleet to anywhere in the world at a moment's notice. The streaming of high-definition (HD) video over a shipboard network requires significant bandwidth with ultra-high definition (UHD) demanding even more. Despite the need for increased network capability, the Department of Defense (DOD) networks have not kept pace with the bandwidth demands of digital video, with deployed units being the most negatively impacted. As video quality continues to increase and video streaming becomes more imperative, the ability to link ship-based assets with video distribution outlets will require the utilization of recently developed, commercially available, high-throughput satellite communications. The high bandwidth afforded by these networks can enable the delivery of high-quality video to consumers during at-sea periods for a wide variety of use cases and applications.

A. PROBLEM AREA

Commander Naval Force Atlantic (CNAL) identified U.S. aircraft carriers' ability to distribute HD quality video from remote locations as a critical mission requirement. UHD video consumes more network and computational resources than lower resolutions. Existing network capabilities used by military are insufficient, as UHD video requires the use of high-speed networks and emerging high-throughput satellite systems for content delivery from remote locations. Existing military satellite communication (SATCOM) systems are limited in their ability to provide required bandwidth for the transmission of lower resolution HD video. The lack of video collaboration from geographically separated personnel contributes to the delay of time-sensitive content delivery in many public affairs operations.

B. OBJECTIVES

The purpose of this thesis is to provide a recommendation through the evaluation of a field-deployable video cloud server used in conjunction with the O3b transportable medium earth orbit (MEO) tracking fly away antenna system (TFAAS). Server hardware and software will be evaluated and tested for video collaboration and real-time content editing of UHD video, which will enhance public affairs capabilities when operating from isolated locations. The results will provide managers with an option to enhance the aircraft carrier's ability to manage UHD video.

C. RESEARCH QUESTIONS

- What are the data transfer practices utilized within the U.S. Navy and how can they be improved by emerging high-throughput satellite systems?
- Can a process to balance video quality with available bandwidth and storage constraints be identified and implemented within current operating procedures or future procedures for public affairs operations?
- How will the high-throughput capability associated with the Other Three Billion (O3b) Networks satellite system integrate with the Naval Postgraduate School (NPS) Field-Deployable Video Cloud Solution to facilitate file transfer and collaborative workflows in a deployed environment?

D. METHODOLOGY

This research uses a mixed-method approach utilizing both qualitative and quantitative techniques for our evaluation. The primary experiments include testing various video quality settings, using emerging compression schemes and common containers for HD video delivery, and evaluating the O3b Networks portable satellite system. The architecture of the satellite system allows for multiple signal inputs; therefore, experimentation and testing occur on personal data devices, laptops, and desktop computers in an effort to validate this capability. Satellite evaluation is conducted to collect performance data to determine if the results meet the engineering requirements.

E. SCOPE

The scope of this research is focused strictly on the NPS Field-Deployable Video Cloud Solution and the O3b Networks portable satellite system. Testing performed on these systems adheres to the engineering requirements established by CNAL and Office of Naval Research (ONR) Tech Solutions office. Understanding how O3b Networks satellite systems can be implemented by deployed units in support of public affairs demands is critical to this research and is discussed in Chapter II. This research fosters the adoption of these emerging technologies within the U.S. Navy and provides recommendations for public relations entities within DOD.

F. BENEFITS OF STUDY

Successfully applying technology is key to enhancing military operations. Implementing high-throughput satellite communications for video transfer will enhance the Navy's capability both tactically and strategically (e.g., battle damage assessment and humanitarian assistance/disaster relief). The Medium Earth Orbit (MEO) satellite solution evaluated within this research proves to be a superior asset when compared to GEO satellite systems. When coupled with the NPS Field-Deployable Video Cloud Solution, it addresses the lack of HD content delivery by U.S. aircraft carriers.

G. THESIS OUTLINE

The remainder of the thesis is presented as follows:

Chapter II establishes the background pertinent to this research. This chapter introduces and discusses SATCOM and different SATCOM systems. An overview of digital video, associated compression schemes, containers, and players is presented. Finally, the digital video infrastructure and concerns are covered.

Chapter III covers the specific O3b satellite component in addition to the NPS Field-Deployable Video Cloud Solution hardware and architecture makeup.

Chapter IV presents the system evaluation and implementation. System evaluation was conducted using qualitative and quantitative analysis at Marine Corps Base Camp

Pendleton and in the NPS digital video lab. This section also includes the evaluation setup for the system.

Chapter V comprises the research summary, recommendations, future research opportunities, and the thesis conclusion.

II. BACKGROUND

With the arrival of HD and UHD resolution and advanced compression techniques, the need for high-speed networks, increased computational capability, and emerging satellite technology for content delivery is an evolutionary process on which the U.S. Navy (USN) must embark. The commercial SATCOM industry has benefited from military contracts to supplant military SATCOM shortcomings and has readily available connectivity options for customers. The exploration of emerging satellite capabilities and digital video processing techniques will aid the USN in obtaining a robust field-deployable video cloud solution in support of public affairs missions in remote locations.

A. SATCOM

1. Naval Implementation

Although the U.S. military is implementing newer and more advanced communication satellites such as Advanced Extremely High Frequency (AEHF), according to published sources, about 80 percent of all military satellites come from commercial sources (Lee & Steele, 2014). According to Lee & Steele (2014), "Regardless of how much capacity is increased by the launch and deployment of military satellite communications systems, there will always be a need to supplement this capacity with the purchase of bandwidth on commercial satellite systems" (p. 5). Just as demand for more and more bandwidth increases in the general population, so it does in the military.

Commercial satellite sources are disadvantaged and do not have defensive capabilities built into them initially, such as jam resistance and secure communications, but additional hardware can provide these capabilities at an additional cost and potential throughput reduction. These capabilities are common requirements of military-grade communication equipment. With no big plans in sight to build commodity Internet satellites, the U.S. military will continue to lease these resources from commercial

sources. This thesis explores the augmentation of current capabilities with high-speed satellite Internet capacities to support large file transfers of video content.

Current Internet throughput rates for U.S. Navy aircraft carriers are around 20 megabits per second (Mbps) and below (O3b Government, 2015). These high data rates are typically achieved by aggregating multiple systems in tandem. According to Defense Industry Daily,

> The Navy expects to eventually deploy 200 of the high-capacity terminals, which will be able to send data at a speedy 21.4 Mbps as opposed to the current Inmarsat and Commercial Wideband Satellite Program terminals, which can only send data at 4 Mbps. (2010)

Currently, aircraft carrier systems use multiple 4 Mbps systems to achieve throughput. If the 4 Mbps systems are replaced by 21.4 Mbps systems, it will be a great improvement, but is still not ideal even as a standard today. O3b Networks, a relatively new provider of satellite services, has the potential for 1.6 gigabits per second (Gbps) per channel and would essentially allow for a paradigm shift in media transfer for the U.S. Navy (Technology, n.d.).

a. Challenge Athena

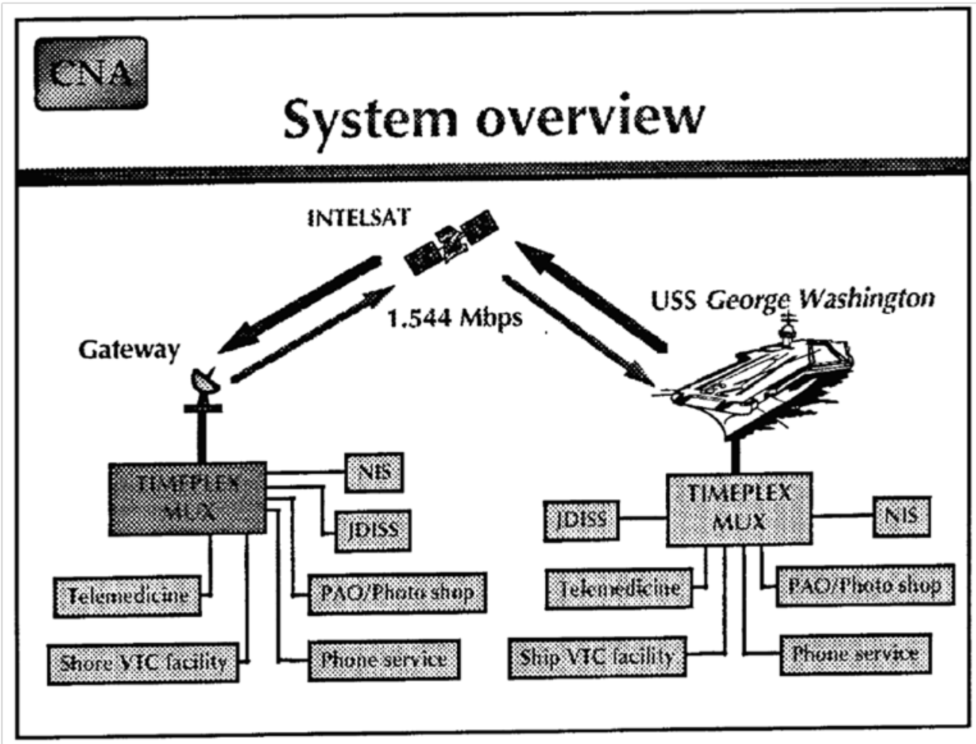
(1) Challenge Athena I

According to Clancy (1999), "During Desert Storm, none of the U.S. Navy carriers had the ability to receive the daily Air Tasking Order (ATO) from United States Central Command's (CENTCOM) air command" (p. 119). This required the use of fax machines over telephone lines to deliver the ATO to ground personnel and the Navy had to rely on paper copies delivered by aircraft. Something needed to be done about this lack of connectivity involving naval assets. Challenge Athena I was an experiment executed on the *USS George Washington* (CVN-73) and allowed for a two-way, approximately 768 kilo-bits per second (Kbps), commercial satellite connection in hopes of passing not only large amounts of text but also photos and video (Clancy, 1999).

(2) Challenge Athena II

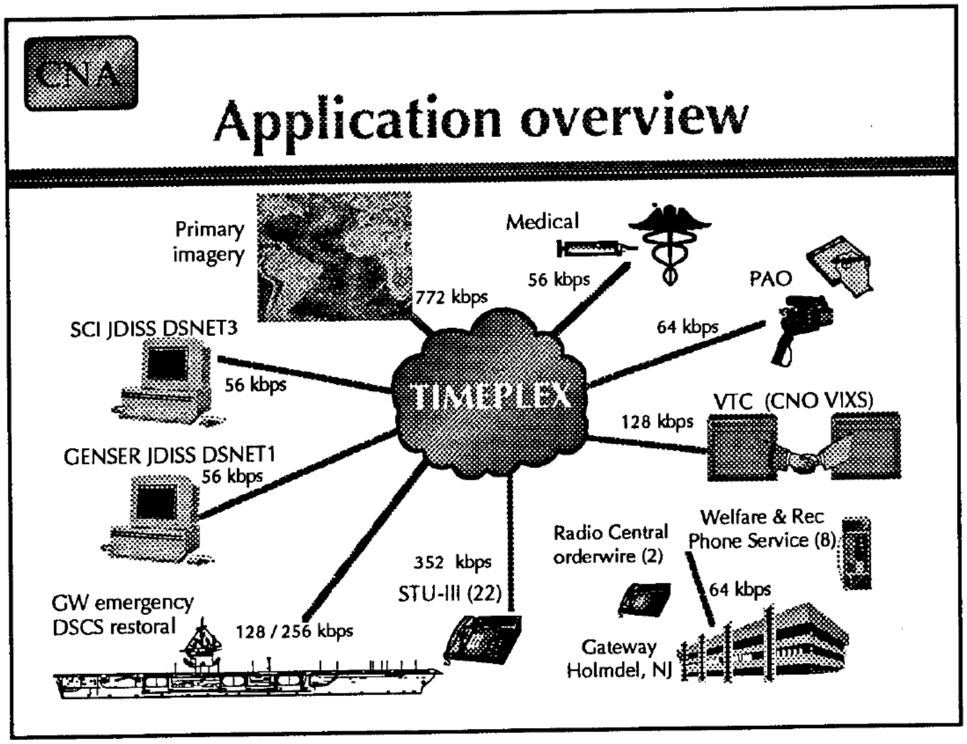
Project Challenge Athena II, topology displayed in Figure 1, was a continuation of Challenge Athena I and displayed high-throughput capabilities to the George Washington battle group under operational conditions in 1994 (Profio & Hess, 1995). Figure 1 shows how the commercial satellite with T1 bandwidth (1.544 Mbps) used half of the bandwidth for imagery and the other half for telemedicine and telecommunication (Profio & Hess, 1995). The demonstration successfully proved, as illustrated by Figure 2, to be reliable and able to send and receive large quantities of imagery (Profio & Hess, 1995). Video teleconferencing was also a success (Profio & Hess, 1995). System availability was 96 percent throughout the deployments with an average downtime of 20 minutes per occurrence (Profio & Hess, 1995). Major reasons for downtime included electromagnetic interference (EMI), antenna blockage, and shore problems (Profio & Hess, 1995). EMI from SPY-1 radar was the cause of the most downtime and could affect the ship from 25 nautical miles away.

Figure 1. Challenge Athena II System Overview



Source: Profio, J. & Hess, B. (1995). Challenge Athena II analysis results: EUCOM/CENTCOM deployment of George Washington Battle Group. Arlington, VA: Center for Naval Analyses.

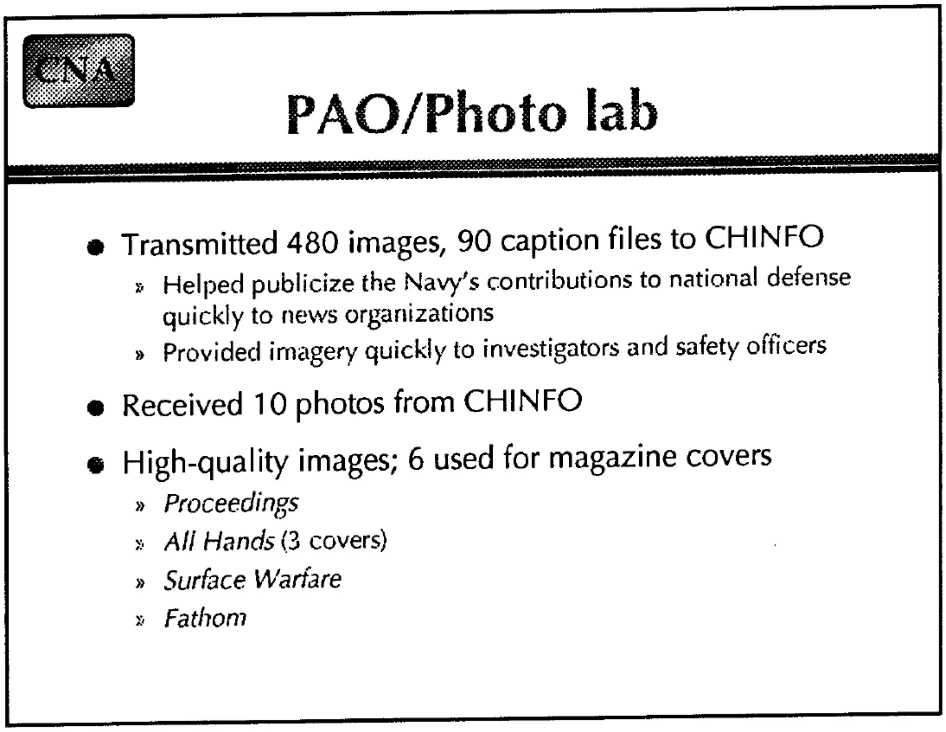
Figure 2. Challenge Athena II Application Overview



Source: Profio, J. & Hess, B. (1995). Challenge Athena II analysis results: EUCOM/CENTCOM deployment of George Washington Battle Group. Arlington, VA: Center for Naval Analyses.

Figure 3 shows the various uses of the satellite data. Take note that the Public Affairs Office (PAO) was allotted 64 Kbps.

Figure 3. Challenge Athena II PAO/Photo Lab



Source: Profio, J. & Hess, B. (1995). Challenge Athena II analysis results: EUCOM/CENTCOM deployment of George Washington Battle Group. Arlington, VA: Center for Naval Analyses.

2. Current Systems

The satellite systems that the U.S. Navy utilizes for communications have always been geostationary, which is to say that the satellites orbit at the exact speed of the earth's rotation keeping them stationary over a spot on earth. Huckell and Parsons (1999) stated,

> There is still considerable use of low rate message services (mostly 75 bps teletype networks), but secure voice, messaging networks, and information exchange networks operating at 2400 bps are the major users of ultra-high frequency (UHF) resources. UHF military satellite communications (MILSATCOM) is often used by early entry forces then replaced by large SHF and EHF communication systems as soon as possible. (p. 18-3)

Although these UHF resources are mainly for low-rate messaging, it starts to show the exponential increase in demand that comes with the increasing needs of the military.

a. Mobile User Objective System

Mobile User Objective System (MUOS) is the replacement for the aging UHF Follow-On (UFO) system and specialized in being a robust military communication system although with limited data rates of 2.4 Kbps up to 384 Kbps (Oetting & Jen, 2011). It uses four geosynchronous satellites and an on-orbit spare. This system is used mainly for ground voice and data operations and is not designed for sending images or video from deployed ships.

b. MILSTAR and AEHF Systems

Military Strategic and Tactical Relay (MILSTAR) is a system that is comprised of five satellites, and enables secure and resilient communications globally for the U.S. Military (Lee & Steele, 2014). These $800 million satellites can achieve a medium data rate from 4.8 Kbps to 1.544 Mbps. AEHF is designed to eventually replace the aging MILSTAR system and be able to transmit mission essential video, navigation and position information, and data required for engagement exclusively for military applications" (Lee & Steele, 2014).

c. DSCS and WGS

Defense Satellite Communications System (DSCS) is another aging geostationary satellite system that provides high volume and secure voice and data communications (Lee & Steele, 2014). Although successfully in operations past its ten-year service life, it will be replaced by the Wideband Global SATCOM (WGS) system that is designed for medium to high data rates (Lee & Steele, 2014).

There is no single solution to provide the U.S. Military with a global, robust and resilient satellite communication capability. Diversity of systems is important, but none of the current systems are capable of sustained data transfer rates to routinely transmit the

large files associated with HD video suitable for broadcast in support of Public Affairs Offices in the U.S. Navy. It is important to identify commercial satellite services that will support HD video data rates that range from 25 Mbps to over 250 Mbps because digital video in its many formats has emerged as the most important medium for public affairs outreach.

B. DIGITAL VIDEO

1. Background

Digital video has become a ubiquitous communications tool, yet DOD networks, especially shipboard networks have not kept pace with the bandwidth demands of digital video. High-speed satellite communications linking ship-based assets will be required as video complexity increases and video recording and streaming become more important and widely deployed. With broadcast video allowing for multiple signal inputs, configurable workflows and new coder/decoder (codec), emerging techniques must be identified and evaluated too. During intermittent or low-bandwidth network environments, satellite technology may be utilized to deliver such products to customers during at-sea periods for a wide variety of use cases and applications. The Navy has established the need for more video services and distribution from anywhere in the world and within the fleet.

a. Tactical Video

In the tactical domain, digital video has enabled commanders to have a real-time battlefield picture from manned and unmanned assets orbiting overhead. This capability has provided a tactical edge to warfighters. With the introduction of HD video, emerging satellite technologies and increased available bandwidth, greater resolution can be achieved. With these technological advances in digital video distribution, it is likely that the use of HD tactical video will become pervasive, forcing the procurement of more video sources and distribution methods. In the case of homeland security, unmanned aerial vehicles are a force-multiplier, giving additional capabilities without additional

personnel that typically are required to detect and deter illegal intrusions into the United States (Haddal & Gertler, 2010).

b. Non-Tactical Video

Digital video is ubiquitous in non-tactical settings. Several online digital video services are available for content storage and video on-demand services. Online video consumption is very popular and, according to Statista, 24 percent of U.S. users are regularly using streaming video services (2015). According to YouTube, almost one-third of all the people on the Internet are users of YouTube and watch hundreds of millions of video files, generating billions of video views (2015).

According to a study performed by the Pew Research Center, 64 percent of Americans own a smartphone as of April 2015, up from 58 percent in early 2014 (Smith, 2015). With smartphone proliferation, users have become dependent on these devices for everyday tasks ranging from banking, personal health monitoring, real estate assistance, and even educational content delivery (Smith, 2015). The Pew Research Center conducted a survey revealing that 85 percent of Americans respondents between the ages 18 and 29 own a smartphone. This age bracket accounts for 68 percent of the U.S. active duty military force (Demographics of Active Duty U.S. Military, 2015). With HD and UHD viewable content on smartphones, the demand for UHD video is growing. We have gone from a world where there were many small streams and a few large streams (webpages) to a world where there are many large streams on many platforms.

USN and DOD personnel reflect this trend and both official and non-official communications transiting DOD networks are increasingly media rich. From advertising to video teleconferencing, digital video technology is maturing to meet the industry demand for higher resolution quality content delivery. Experimental testbeds are pushing quality and bandwidth requirements even further, providing a picture of the near future.

During the 2014 Global Lambda Integrated Facility (GLIF) Workshop, Research and Education Advanced New Zealand (REANNZ) demonstrated a "high resolution, multi-point telemedicine application for use in dermatology clinical education; cancer

epidemiology; and for remote examination, diagnosis, dermatopathology and patient counseling of skin cancers" in active duty and veteran populations (Weekley, 2014). The demonstration involved a remote collaboration of a patient located in San Diego, a primary care physician consulted from New Zealand, and a dermatologist from Chicago. Each participant was able to see the 4k UHD live-stream of the patient as the technician "scanned" the area of clinical concern. All three locations had a HD live-stream of the respective environment of the other two locations (e.g., a medium or long shot of the doctor watching the big screen with the 4k stream). There was the option of presenting one's own live stream on the local screen, as well for feedback purposes. Thus, the demonstration created a kind of virtual environment where the collaborative efforts of each party could see each other and the patient in real-time over great distances with little latency, excellent audio synchronization and multiple views. This use of UHD video over long distances has the potential to pave the way for future medical procedures where the patient and medical expert are geographically separated.

This is one example of how UHD video is moving beyond the typical teleconference and impacting healthcare. Other potential application areas include: shipboard maintenance (imagine not having to fly technicians to ships for repairs, but rather 'teleporting' them there via high-speed networks and portable 4k), collaboration for training and education, legal proceedings, and other applications that demand critical viewing of detail and where close collaboration is required.

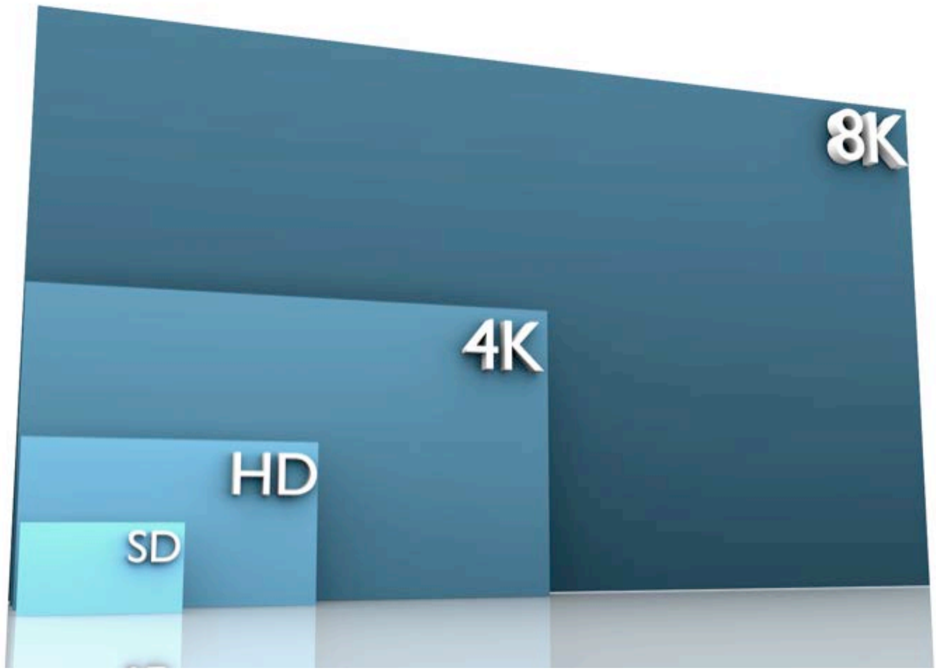
Meanwhile, digital video continues its march towards larger formats, higher frame rates and more colors. At the International Broadcaster's Conference (IBC) 2015 in Amsterdam, a German engineering firm, Cinergy, debuted an intermediary codec called "Daniel 2" capable of decoding up to 1100 frames per second at 8k – which is equal to over 4300 frames per second (fps) in 4k (8k is quad 4k) or 17,000 frames of full HD per second (8k is 16 times HD). The specification allows for up to 280 frames per second of 16k at 15360 x 8640 pixels (4 times 8k, 16 times 4k and 64 times HD) with compression ratios of 1:10 to 1:20 (2015). All of these qualitative improvements require higher bandwidth as the video files and streams are almost always transported, manipulated, shared and stored using a network.

2. Resolution

In the 1980s and 1990s, the standards for interlacing Analog Standard Definition (SD) and HD into digital video formats were developed leading to the well-known International Telecommunication Union (ITU) Recommendations 601 (SD) and 709 (HD) 1920x1080 and 1280x720 image format standards. These are known as Society of Motion Picture and Television Engineers (SMPTE) ST 274 and ST 296 respectively (Hudson, 2012). However, unlike photochemical film or analog video broadcasts, digital video encompasses a myriad of resolutions and formats.

Before Internet Protocol (IP) was a common transport method, these SD/HD streams used serial digital interfaces (SDI) to transport the signal between components of the video network. Video was all streaming and file-based workflows were uncommon at this time. While early versions of SDI were designed for bitrates of 270 Mbps, standardized by SMPTE ST 259 and more recently 1.485 Gbps, standardized by SMPTE ST 292, higher frame rates, higher dynamic range and increased bit depth have taxed these standards and push for new methods of delivery (Hudson, 2012). Video resolution has historically been categorized as low resolution, SD, HD and UHD. Figure 4 shows a digital video resolution comparison. Technically speaking, HD is anything above SD and UHD is anything above HD. The terms are purposefully vague due to the varying international broadcast standards, proliferation of camera types and display options.

Figure 4. Digital Video Resolution Comparison



Source: Baxter, A. (2015). 8k and the future of resolution [Online Image]. Retrieved September 21, 2015 from https://www.eclipsewebmedia.com/ 8k-future-resolution/

a. *Standard Definition*

Resolution below HD is SD. In the U.S., typical SD resolution is 480 interlaced lines of horizontal resolution (480i) where even and odd lines are scanned alternately across a display device, typically an analog cathode ray tube (CRT) display. This resolution is common in broadcasting content for non-HD television units. For digital display, 480 lines of horizontal resolution are progressively scanned. Stacked one by one on top of each other, 480 lines scanned gives 480 pixels high, thus converting horizontal scan lines into vertical pixel dimension yields 480 pixels high. SD has an aspect ratio of 4:3, so at this aspect ratio, a 480i signal would build a picture that is 480 x 640. Strictly speaking, analog signals cannot be described in pixels, but Society of Motion Picture and Television Engineers (SMPTE) Rec. 601 allows U.S. this description for illustrative purposes.

b. High Definition

Resolution that is above SD is considered to be HD. 720p resolution is 1280x720 (1280 pixels wide and 720 high). 720p video is covered within the SMPTE 296 standard. 1080p resolution is 1920x1080 (1920 pixels wide and 1080 high). 1080p video is covered within the SMPTE 274 standard. While there is such a thing as analog, HD, from this point forward, formats described are digital in nature.

c. Ultra-High Definition

Academy 2k resolution is 2048x1080 (2048 pixels wide and 1080 high) and totals 2.2 Megapixels. Academy 4k resolution is 4096x2160 (4096 pixels wide and 2160 high) and totals 8.8 Megapixels; UHD 4k is really quad HD at 3840 x 2160 and is typical for broadcast applications. 8k resolution is 7680x4320 (7680 pixels wide and 4320 high, or quad 4k) and totals 33.2 Megapixels. While standards defining this resolution have not emerged from international standards groups, NHK of Japan is proposing their 8k format be adopted as UHD 8k. Already there are cameras capable of 8k capture and prosumer (a portmanteau of professional and consumer which occupies the middle ground) 8k televisions are available for over $130,000 (Kelion, L., 2015).

With 4k becoming more mainstream and 8k an emerging capability, you can see from Table 1 the amount of bandwidth required for delivery of the increased frame rate and color depth payloads for uncompressed and lightly compressed transmission.

Table 1. Image Formats and Payloads for 4k and 8k Production

<table>
<tr><th rowspan="2">System Nomenclature</th><th rowspan="2">Horizontal Pixels</th><th rowspan="2">Vertical Pixels</th><th rowspan="2">Frames per Second (nominal)</th><th colspan="2">Total Payload (nominal)</th></tr>
<tr><th>10-bit 4:2:0
10-bit 4:2:2</th><th>12-bit 4:2:0
12-bit 4:2:2
12-bit 4:4:4
10-bit 4:4:4:4</th></tr>
<tr><td>4320p60 / 59.94</td><td>7680</td><td>4320</td><td>60</td><td rowspan="2">48Gbit/Sec</td><td rowspan="2">96Gbit/Sec</td></tr>
<tr><td>4320p50</td><td>7680</td><td>4320</td><td>50</td></tr>
<tr><td>4320p30 / 29.97</td><td>7680</td><td>4320</td><td>30</td><td rowspan="3">24Gbit/Sec</td><td rowspan="3">48Gbit/Sec</td></tr>
<tr><td>4320p25</td><td>7680</td><td>4320</td><td>25</td></tr>
<tr><td>4320p24 / 23.98</td><td>7680</td><td>4320</td><td>24</td></tr>
<tr><td>2160p60 / 59.94</td><td>3840 / 4096</td><td>2160</td><td>60</td><td rowspan="2">12Gbit/Sec</td><td rowspan="2">24Gbit/Sec</td></tr>
<tr><td>2160p50</td><td>3840 / 4096</td><td>2160</td><td>50</td></tr>
<tr><td>2160p30 / 29.97</td><td>3840 / 4096</td><td>2160</td><td>30</td><td rowspan="3">6Gbit/Sec</td><td rowspan="3">12Gbit/Sec</td></tr>
<tr><td>2160p25</td><td>3840 / 4096</td><td>2160</td><td>25</td></tr>
<tr><td>2160p24 / 23.98</td><td>3840 / 4096</td><td>2160</td><td>24</td></tr>
</table>

Source: Hudson, J. (2012). *1080p50/60, 4K and beyond: Future Proofing the Core Infrastructure to Manage the Bandwidth Explosion*. Paper presented at the SMPTE Annual Technical Conference: Ultra-high definition imaging session, Hollywood, CA. Retrieved from http://www.smpte.org

It’s unlikely that U.S. broadcasters will be eager to begin widespread transmission of 4k or 8k, but already NHK of Japan and TVGlobo of Brazil have broadcast compressed 4k over terrestrial broadcast systems and tested 8k transmissions over IP to special venues in Japan and Brazil for the 2014 World Cup with plans to do the same for the 2016 Olympics.

A more likely scenario is that these formats will emerge as options for video-on-demand services such as Netflix and YouTube. Many productions are already capturing in 4k, so it is relatively realistic to expect more and more content delivery in this format. YouTube supports 8k encodings and there are some test and experimental short films available, though few have the display to see them in their native formats. The trend is clear though: resolutions and the bandwidth required will continue to increase.

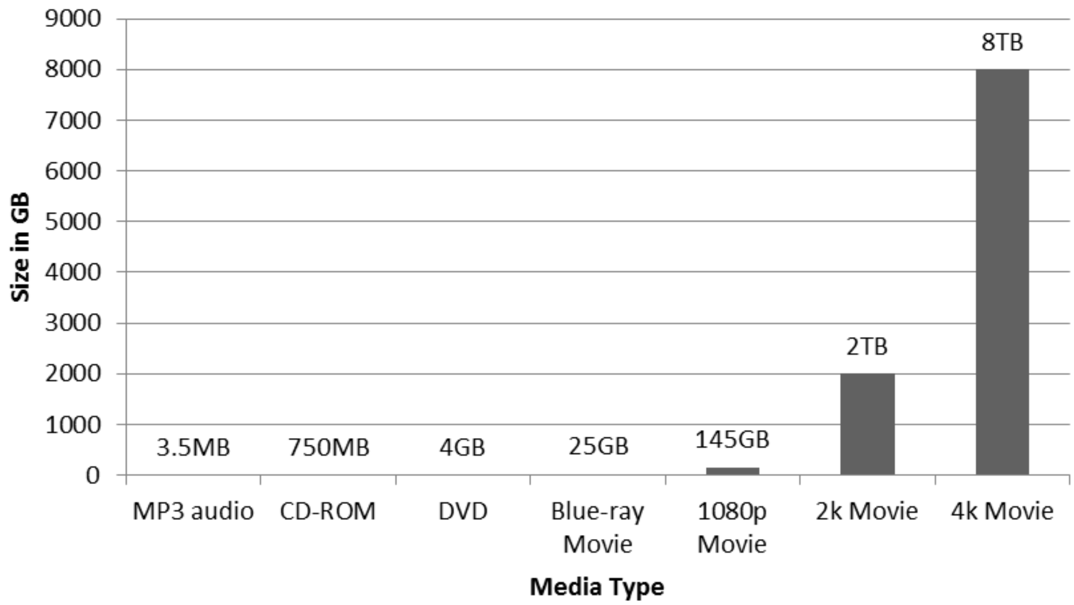
3. Compression

As technological advancements have delivered increased spatial resolution for televisions, increased processing power, ultra-high speed and fiber-to-the home Internet, more people are watching HD and 4k content than ever before. According to 2014 data, 77 percent of U.S. homes have at least one HD television (Burgner, 2014). Many new

“smart” televisions can connect directly to the Internet using WiFi, giving them the ability to receive streams of content from popular providers such as Netflix, Hulu and YouTube. Legacy televisions can be retrofitted with inexpensive set-top devices such as AppleTV or Chromecast that allow the television to display streaming content. While the FCC’s definition of broadband is 768 Kbps, this seems slow by today’s standards. An estimated 70 percent of Americans have always-on broadband connections of some sort (Patel, 2008). According to the Pew Research Center, of the 64 percent of American adults who own smartphones, 89 percent have access to high-speed Internet through their mobile devices, which themselves are capable of HD and sometimes 4k display of content (2015).

The entertainment industry generates tremendous amounts of data for each title that is created and most require extensive post-production efforts to achieve the desired artistic outcome. This is especially true for digital cinema, but many scripted television programs are similarly produced. With different resolutions available for directors and cinematographers to choose from, the distributors are challenged to deliver the product to many different platforms (TV, tablet, digital cinema projector) over an ever-increasing number of distribution channels (broadcast, Internet, theatrical release) and even across regulatory and cultural boundaries. Each of these content delivery methods impose limitations on the content provider that requires the use of techniques such as compression, retiming (for instance to go from a 24 fps theatrical release to a 50hz broadcast in New Zealand) to allow for video viewing. Figure 5 depicts a comparison of file size from different mediums utilized on a typical two-hour theatrical picture.

Figure 5. Typical Two-Hour Theatrical Picture



Source: National Archives. (n.d). *Digital Moving Images from Film-based Source Material.* Retrieved 20 August, 2015 from www.archives.gov/preservation/ products/reformatting/mopix-digital.html

a. Compression Techniques

When dealing with content delivery, file size has the potential to impose large restrictions on distribution. File size is dependent on both bit rate and content length. Bit rate is a value measured in bits per second (bps) and is related to the compression ratio of the file. The upper limit to bit rate is set by bit rate of the uncompressed video. The lower bound is typically dictated by distribution channel. For instance, Blu-ray digital versatile disc (DVD) authors know the Blu-ray disk readers have a maximum disk read speed of 54 Mbps and so will compress a title to fit within that speed (typically well below that speed to allow for more content per disk). Digital cinema typically operates in the 150–200 Mbps range and is delivered on specialized disk arrays with high capacity, so less compression is required. Dynamic imagery (fast action) requires higher bitrates than less dynamic imagery (car chase versus romantic dinner scene). These images with smaller bit rates set during the encoding process are susceptible to artifacts, which are present when the bit rate chosen is set too low.

Video compression is a balance between file size and image quality. Some encodings, especially for DVDs and BluRay disks, allow for variable bit rate. Overall video quality is based on a variety of things to include bit rate, frame size, frame rate and the action in frame. Frame rate is the number of frames that appear in a video every second. The higher the frame rate that is chosen the higher the yield resulting in better simulation of motion, but increased file size and requires processor intensive utilization by the end user during playback. Frame size is a measurement of the number of pixels both vertically and horizontally (e.g., 1920x1080). During compression, taking into account these variables to achieve the desired video quality is a balancing act that takes time and practice to master.

Since compression algorithms are based on the limitations of human vision, two types of schemes arise; lossy and lossless. Lossy compression is where the data after decompression is not necessarily the exact data that was initially compressed, resulting in image degradation or loss altogether. Lossless compression is where the resulting file after compression and then decompression is identical to the original file, but is seldom used due to being inefficient in reducing the file size. Compression is often described as a ratio of the compressed image compared to the uncompressed image (Stump, 2014). The higher the ratio of the compressed image, the more image degradation has taken place. This becomes more evident in post-production when color correction occurs, revealing artifacts in the image.

There are primarily two types of image compression techniques, intraframe and interframe. Interframe compression analyzes multiple frames and only stores the differences between them. Key frames are inserted in certain intervals in video clips to be used as a main point of reference for the subsequent frames. Video that is highly motion saturated will require additional key frames for reference points during the encoding process. A comparison of frames to key frames is constantly taking place throughout this compression technique and results in a more reduced file size after compression. Intraframe compression is used on a single frame, not taking into account any surrounding frames. Stump states that the image integrity of intraframe compression is vastly superior to interframe, but both are still lossy compression schemes (2014).

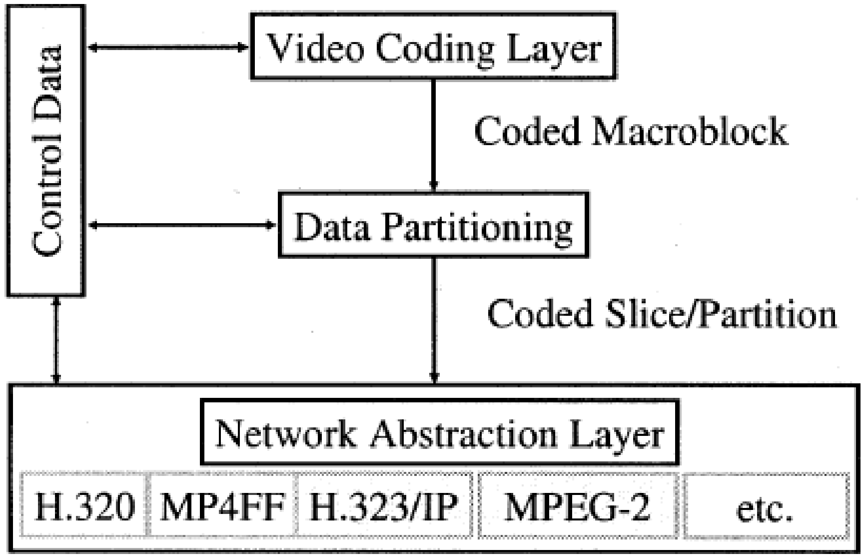
b. Current and Future Standards

Codec is an algorithm that is used to control how video files are compressed during the encoding stage and then how they are decompressed during playback. Communication issues arise in the form of obtaining original content with optimal resolution and a bit rate that can be handled by most home networks and broadband Internet connections (Sullivan & Wiegand, 2005). Bit rate and fidelity are paramount during the encoding process and bandwidth is always a concern. With high-definition television (HDTV) and Ultra HDTV (UHDTV) becoming more prevalent in today's marketplace, the need for higher coding efficiency is a concern for content delivery. While there are many codecs to choose from, listed below are the most common.

(1) H.264

H.264 is an efficient codec that enhances a myriad of applications reliant on video transportation over networks potentially not suited for the high bandwidth demand associated with video. (Dominguez, Villegas, Sanchez, Casas & Rao, 2014). H.264 consists of two layers: video coding layer (VCL) and network abstraction layer (NAL). The VCL represents the video content in a compressed bitstream while the formatting of the information from the VCL by the NAL occurs and formulation of header data used by the transport layers or for archiving. With a 50 percent reduction in bit rate when compared to previously compressed content with equal image quality, H.264 is an attractive option for use (Wiegand, Sullivan, Bjontegaard, & Luthra, 2003). Typical employment of this codec is DVD, Blu-Ray, online video content, 4096x2304 (4K) 60 fps broadcast television content. Figure 6 depicts the structure of H.264/advanced video coding (AVC) video encoder.

Figure 6. H.264/AVC Structure

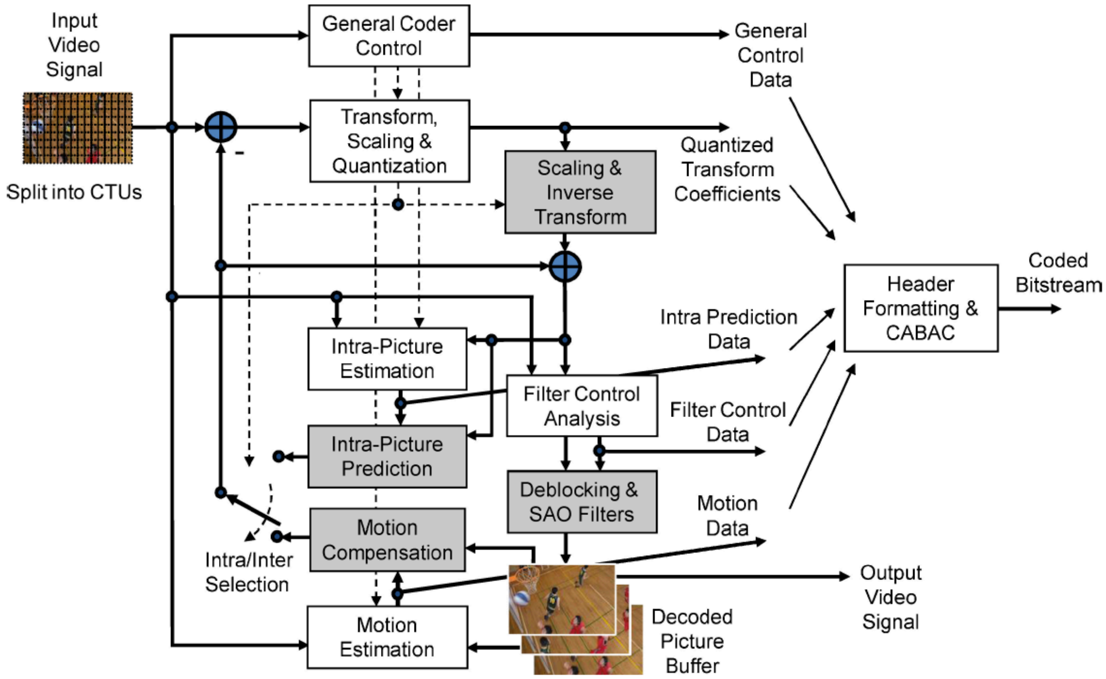


Source: Wiegand, T., Sullivan, G. J., Bjøntegaard, G., & Luthra, A. (2003). Overview of the H. 264/AVC video coding standard. *IEEE Transactions on Circuits and Systems for Video Technology, 13*(7), 560–576. doi: 10.1109/TCSVT.2003.815165

(2) H.265

H.265, also known as high efficiency video coding (HEVC), was ratified by the ITU-T in 2013 as a successor for H.264 (McGuinness, Balster, Priddy, 2015). Despite how efficient the compression, H.264/Moving Picture Experts Group (MPEG) 4 AVC faces adversity when handling HD content on mobile devices and local area networks (LAN), due to the increased available resolutions and saturated network traffic from video. (Henot, Ropert, Tanou, Kypreos, & Guionnet, 2013). HEVC will resolve high video quality and high bitrates by reducing the required transmission capacity while achieving the same video quality. HEVC will allow HDTV and UHDTV content to reach maximum users with the proliferation of 4K televisions and smartphones/tablets able to view the content. As industry strives for enhanced compression techniques, several factors must be considered with computational resource consumption at the top (Uhrina, Sevcik, Frnda, & Vaculik, 2014). Figure 7 depicts a typical HEVC video encoder.

Figure 7. A Typical HEVC Video Encoder



Source: Sullivan, G. J., Ohm, J. R., Han, W. J., & Wiegand, T. (2012). Overview of the high efficiency video coding (HEVC) standard. *IEEE Transactions on Circuits and Systems for Video Technology*, *22*(12), 1649–1668. doi: 10.1109/ TCSVT .2012.2221191

(3) VP8

VP8 was an alternative to H.264/AVC and the concepts are similar to H.264. With VP8 having a Berkeley software distribution (BSD)-like agreement and the promise of being royalty free makes it an appealing choice for compression (Feller, Wuenschmann, Roll, & Rothermel, 2011). VP8 was designed to be an alternative to H.264 AVC for web video applications. When encoding video with VP8 and H.264, the results yielded a reduction in time by 350 percent when H.264 was utilized on equal content (Feller et al., 2011). Figure 8 shows a comparison of key features of H.264/AVC and VP8.

Figure 8. A Comparison of Key Features of H.264/AVC and VP8

Feature	*H.264/AVC*	*VP8*
References	up to 16	3
I-/P-/B-Frames	✓ / ✓/ ✓	✓ / ✓/ (✓)
interlaced / progressive	✓ / ✓	- /✓
Intra mode	(✓)	✓
MV accuracy	$^1/_4$	$^1/_8$
Subsampling	4:0:0 - 4:4:4	4:2:0
Bit depth	8 bit - 14 bit	8 bit
MB sizes	4×4 - 16×16	4×4, 8×8, 16×16

Source: Feller, C., Wuenschmann, J., Roll, T., & Rothermel, A. (2011). *The VP8 video codec-overview and comparison to H. 264/AVC*. Paper presented at the 2011 IEEE International Conference on Consumer Electronics, Berlin, Germany. doi: 10.1109/ICCE-Berlin.2011.6031852

(4) VP9

VP9 was finalized in June 2013 and is Google's next-generation open-source video codec. A major concern when choosing the optimal codec is bandwidth. VP9 was designed to deliver HD content in a reduced bit stream and only have a slight increase in the complexity of the decoding process (Mukherjee et al., 2013). As compared to H.265 (HEVC), VP9 encoding times were hundredfold longer (Kufa & Kratochvil, 2015).

(5) MMT (MPEG media transport)

MPEG modern transport (MMT) is a transport container and associated protocol for HEVC that has several interested characteristics. While technically speaking, it is not a codec but a convergence of the transport streams from both the broadcasting and Internet Protocol. It replaces MPEG-2 TS (Transport Stream) and allows for HTML5 representation, multiplexing of streams from various sources (compositing "in-the-cloud"), simplified relationship between the transport stream and the file-based format, multi-device delivery, and has advanced quality of service (QoS) features. It is specifically designed to handle UHD 4K/8K such that content transformation across platforms and channels is minimized.

c. Impact on Video Quality

Video quality is based on a variety of things, which include bit rate, frame size, frame rate, and the movement of the subject within the frame. Accumulated differences over time result in less efficiency in compression. In other words, a “still life” image of a vase with flowers on a table will compress more efficiently than a car chase. Compression is the balance between file size and bitstream requirements against image quality. Using compression requires understanding of its principles and applications, as poorly compressed materials have artifacts, such as aliasing, color-blocks and signal clipping.

4. Containers

Video containers (i.e., wrappers) contain video and audio tracks that were encoded with a specific codec that allow uniform playback of audio and video on devices. Often the container is the first clue to the operating system in the choice of software to decode and display the video. Commonly used containers are:

- .avi *developed by Microsoft
- .wmv/.asf *developed by Microsoft
- .mov *developed by Apple
- .mkv *developed by Open Source
- .ogg *developed by Open Source
- AVCHD *developed by Panasonic, Sony
- .mp4 *developed by Moving Pictures Expert Group

Because all of these containers have associated intellectual property, they are often not interoperable and factors other than technical issues may impact their ability to be cross-platform, but they also will likely not support modern codecs. WMV containers are developed specifically to play on Microsoft Operating Systems and require third-party plugins to play on non-windows based platforms. The most widely diverse

container that spans most operating systems and players is the .mp4 container, because .mp4 files must adhere to an industry working group standard, against which any developer can write encoders and decoders, it has become the de facto interoperable standard.

In order to support the widest variety of tools across the most diverse set of operating systems, some manufacturers have developed “Intermediate Codecs,” which are specifically designed for interoperability and low-compression ratios. They tend to be larger in size, as they do not presume efficiencies common to more specific codecs (i.e., they do not often include inter-frame compression). Depending on what stage of the video production/distribution process, different codecs and containers are used, but it becomes an N-squared problem and the complexity can only be managed by policy and careful selection of both source and output formats.

Color management is also exceedingly complex, as each codec describes color differently. Moving from codec to codec will change the color space – sometimes subtly, sometimes dramatically. Results are unpredictable and problematic for the digital cinema industry, but also potentially for other industries such as healthcare. For this reason, the Academy of Motion Picture Arts and Sciences has developed the Academy Color Encoding System (ACES). ACES carefully describes color transformations and encourages software and hardware vendors to declare color spaces and provide transformation matrices for predictability.

5. Players

Transcoding happens when a video is converted from one encoding to another. Since encoding and decoding are separate, but related operations, many media players allow for transcoding of materials, as well as encoding (recording) or decoding (playing back). The following list describes common players.

- **Windows Media Player**: Developed by Microsoft and comes native with the Microsoft operating system. This media player also gives users CD ripping and burning functionality and with current updates to the media player, will

view most common containers used today (Getting started with Windows Media Player, n.d.).

- **QuickTime:** Developed by Apple and is a free multimedia player to download and comes with the installation of the Mac OS. Quicktime supports dozens of containers and add-on components can be installed to support even more containers not commonly used.
- **VLC**: An open source, free, cross-platform solution that plays commonly used containers and codecs. Developed by volunteers and promotes free, open-source multimedia options.

In a modern operating system such as Mac OS X, handling video is a core function. Rather than requiring developers to invent or even implement a stand-alone encoder/decoder or recorder/player, they rely on these functions that are built into the core functionality of the operating system itself. This allows for efficient hardware and software functionality, as many codecs are implemented in the hardware itself. For mobile devices, a system-on-chip architecture is used for power efficiency. Third-party codecs often rely on low-level graphic application program interfaces (API) and operate on the graphics card, vice the general processor. In all of these cases, there is a tight coupling between shared resources available on the operating system and video, as video playback is a paramount concern for manufacturers.

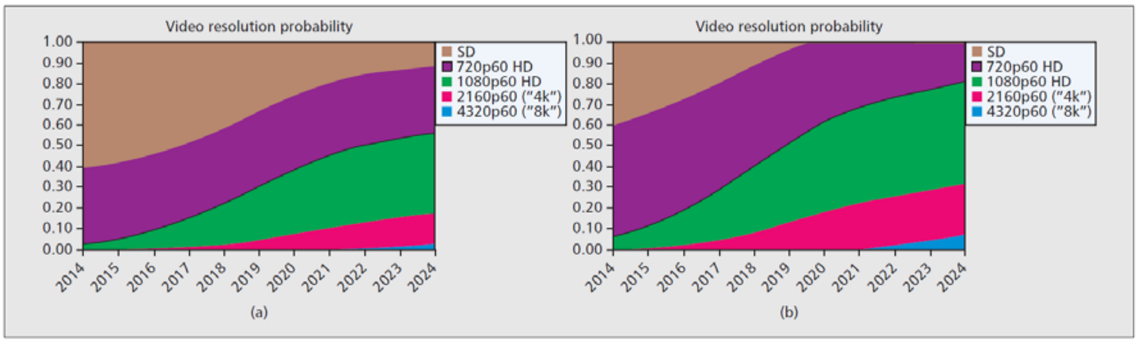
C. DIGITAL VIDEO CYBER INFRASTRUCTURE

1. Emerging Commercial High-Speed Internet

It is important to quantify military and commercial capabilities in order to understand the requirement and demand of digital video delivered through the high-speed Internet. For now, and most likely for a long time, a terrestrial network will have more throughput capability than a satellite network. This terrestrial network will represent the standard for digital video consumption by the public. Naval ships relying on satellites to supply the Internet are at a great disadvantage due to the greatly reduced speeds compared to a traditional network. Harstead and Sharpe (2015) state, “video traffic is by far the largest component of sustained bandwidth and that voice and other primarily audio traffic are comparatively insignificant” (p. 200). Households are relying more on

streaming video for entertainment and news as technology and higher throughput capacity develops. Harstead and Sharpe (2015) expect significant streaming of 4k video in a fixed access network no earlier than 2015, and significant 8k video streaming no earlier than 2020. Figure 9 shows the evolution of high-resolution video adoption. Knowing these trends helps the Navy's public relations community understand what the consumer is accustomed to seeing when watching everyday television or streaming media.

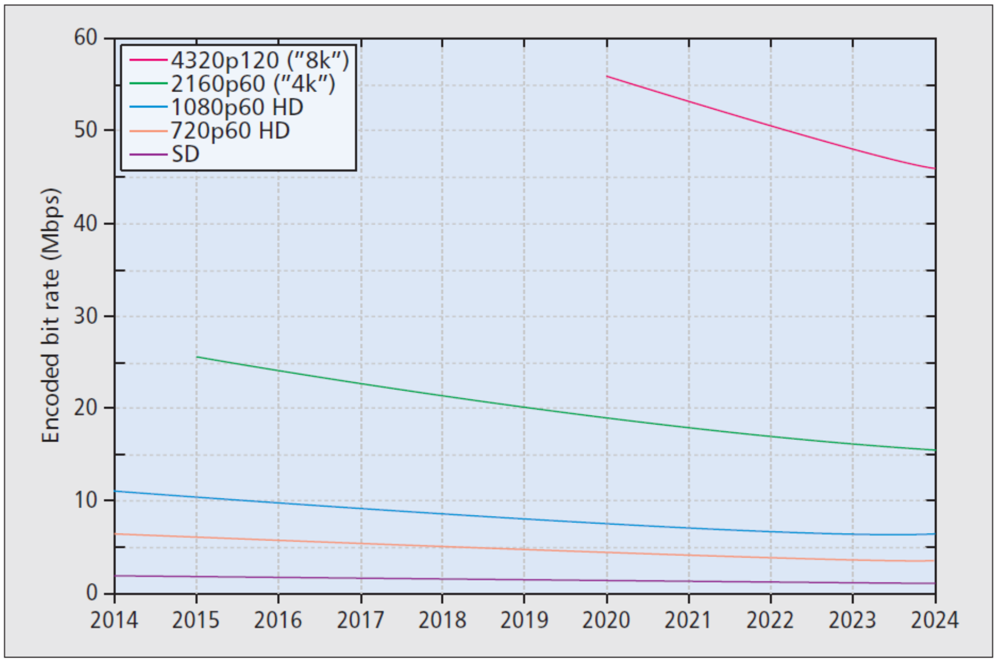
Figure 9. Stream Resolution Probability Distribution Forecast



Source: Harstead, E., & Sharpe, R. (2015). *Bandwidth demand forecasting*. Paper presented at the IEEE 802.3 NGEPON interim meeting, Ottowa, Canada. Retrieved from http://www.ieee802.org/3/ad_hoc/ngepon/public/sep14/harstead_ngepon_01a_0914.pdf

This is the true driver of the increased need for more bandwidth. Figure 10 shows the approximate required bitrate for each different resolution. More efficient encoding slightly decreases the requirement over time. It is estimated that video traffic over the next ten years will grow between 8 and 14 percent every year (Harstead & Sharpe, 2015). Harstead and Sharpe also state Hybrid Fiber-Coaxial (HFC) network transformation must occur rapidly to enable 1 Gbps throughput to handle IP HD video on networks (2015).

Figure 10. Encoded Video Bit Rate Forecasts



Source: Harstead, E., & Sharpe, R. (2015). Forecasting of access network bandwidth demands for aggregated subscribers using Monte Carlo methods. *Communications Magazine, IEEE*, 53(3), 199–207. doi: 10.1109/MCOM.2015.7060505

Typically, consumers use a type of cable or fiber optic Internet service to achieve the highest possible speeds. Out of approximately 50 million high-speed Internet users, cable Internet provides service to 40 percent more households and businesses than digital subscriber link (DSL) and Fiber (Hamzeh, Toy, Fu, & Martin, 2015). Common technology in use by the cable companies is data-over-cable system interface specification (DOCSIS) version 3.0 (2015). Using this technology enables the support of high data rates by combining multiple channels in order to achieve the desired data rate. A throughput of 320 Mbps downstream and 120 Mbps upstream can be supported by DOCSIS using 8 bonded downstream and 4 upstream channels (2015). DOCSIS 3.1 is a newer cable technology being developed and implemented and is capable of throughput up to 10 Gbps downstream and up to 1 Gbps upstream (2015).

Satellite Internet for Home Use

Satellite Internet is becoming a popular option for consumers and businesses that are not able to tap into a terrestrial broadband connection (see Figure 11). Vandermeulen (2015) stated,

> ViaSat is the industry leader in the design and operations of High Capacity Satellites (HCS) with market proven satellites providing broadband to civilian end-users with both direct-to-home and commercial airline Internet services, and to live events, emergency response teams, enterprises, and governments with terrestrial equivalent broadband to a variety of mobile, transportable, portable, and fixed terminals. (p.2)

Its ViaSat-1 satellite provides coverage to North America and has a capacity of 140 Gbps (Vandermeulen, 2015). Typical leased speeds are much lower though as displayed in Figure 12. Typical speed ranges from 1.5–50 Mbps.

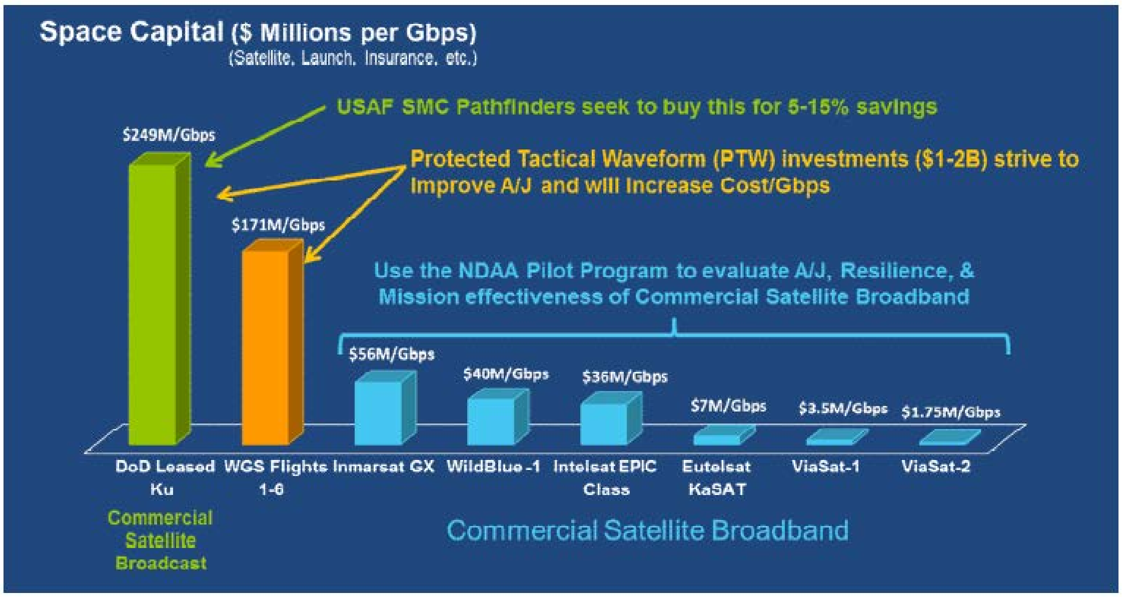
Figure 11. Commercial Satellite Broadband Users

Source: Vandermeulen, R. (2015). Reinventing Space–High Capacity Satellite Communications–Dramatic, Cost-Effective Improvements in Broadband Delivery to Warfighters, Civilians, and Emergency Responders. Paper presented at the AIAA SPACE 2015 Conference and Exposition, Pasadena, CA.

The use of both commercial and military satellites to provide broadband connections is prevalent today, although the commercial industry seems to have the advantage due to a higher level of innovation (Vandermeulen, 2015). The DOD is in a constant debate whether to build and launch its own satellites or lease them from a commercial provider. The U.S. Navy's current satellite broadband requirement is currently 450 Mbps (2015). This quantity mirrors the 12 Mbps connection provided to a typical aircraft carrier (2015). If high-resolution digital video upload and download were included in this broadband requirement this number is likely to increase exponentially.

Although O3b Networks' total single satellite capacity of 16 Gbps is much lower compared to ViaSat's 140 Gbps, leased transponders are capable of providing a much faster connection when compared to the 12 Mbps provided to aircraft carriers (Technology, n.d.). O3b Networks also operates around the globe (within 45 degrees north and south latitude for full service) with its satellite constellation and ViaSat can only provide coverage for the area surrounding North America currently, but plans for expanded coverage are in work.

Figure 12. Commercial Satellite Cost Comparison



Source: Vandermeulen, R. (2015). Reinventing Space–High Capacity Satellite Communications–Dramatic, Cost-Effective Improvements in Broadband Delivery to Warfighters, Civilians, and Emergency Responders. Paper presented at the AIAA SPACE 2015 Conference and Exposition, Pasadena, CA.

2. Current and Near-Future DOD Networks

U.S. naval ships take many years to plan, build, trial, and place into service, as well as retrofit aging shipboard technologies to meet the demand for technological advancements. This means that advanced technologies the designers and builders plan to implement on these platforms can be outdated by the time they actually reach the fleet.

According to official Navy sources, planning for the CVN-21 program began in 2004, when the Navy described it as a 3-ship program encompassing CVN-78 (*USS Gerald R. Ford*) and two follow-on platforms, CVN-79 and CVN-80 (O'Rourke, 2005). In 2004, 4k video was in the prototype stage, with very few prototype cameras, experimental signal processing and limited options for playback and viewing, so it was likely not considered as a technological factor in camera technology to be deployed in the CVN-21 program. HD was the future state-of-the-art, and if accommodation was made for that, it was widely accepted as revolutionary and an end-state for digital video. Therefore, it is unlikely that shipboard networks were designed specifically to handle anything above HD content. It is more likely that current technology for network infrastructure was limited to twisted pair, coaxial cable, and fiber optic cabling. Both twisted pair and fiber optic cabling are upgradeable to support multiple HD video streams or even multiple 4k video streams.

The limitations of legacy technology may cause issues when attempting to transfer large amounts of video data in a short duration. It may even limit video streaming capabilities depending on the quality of the video, compression used and the number of simultaneous video streams being viewed. For example, 10Base2 and 10Base5 coaxial cable is used for certain shipboard applications and is rated at a speed of 10 Mbps. When referring to Table 1, 1080p 60 fps video requires a connection higher than 10 Mbps, which would make it infeasible to use for this application. This does not allow for future growth, especially when UHD 4k video will be common in the near future.

Legacy twisted pair cabling has limitations as well. While CAT 5e is the standard for a 1 Gbps connection, the older and much slower CAT 5 cabling is common on older Naval ships. With 100 Mbps limitations imposed by the use of CAT 5 cabling, network congestion may become a factor in a network of multiple users. Transmission Control Protocol/Internet Protocol (TCP/IP) does not handle network congestion gracefully. At near capacity, packets will be dropped and QoS will suffer. This is particularly impactful on video streaming services and makes live-streaming impossible without the use of Forward Error Correction (FEC) schemes.

A Network Interface Card (NIC) can be a limiting factor for certain networks as well, but are easily upgradable at the client point of use. There are restrictions on the type of network cards and requirements for minimum performance values that are mandated by cyber security policies, but generally speaking, they are commodity items that are easily upgraded. Gbps Ethernet NICs are becoming standard hardware while much faster NICs are also available if the supporting network is provided.

End-point technologies, such as NICs, routers and switches, as well as transmission optics for fiber-optic networks are constantly being improved to gain more bandwidth from legacy networks. CAT 6a will allow for speeds up to 10 Gbps Ethernet (10GE) over balanced twisted pair, but it is unlikely that older shipboard infrastructures are built on this relatively new cable type. There are some approaches to 10GE (10Gbase-T or IEEE 802.3an-2006) which allow for greater than 1GE over CAT5e, but they require higher power due to greater power dissipation. Fiber optics has become the standard for 10GE transmissions.

3. Network Infrastructure Paradox

End-to-end networks are only as fast as the slowest link. In commercial networks, such as home ISPs (Internet Service Provider), providers are dis-incentivized to make upgrades to these networks when there are legacy elements in place, like the connections into the home (e.g., DSL, which may be copper). If the aggregate demand for bandwidth over slower portions of the network does not exceed the speed of the backhaul portion of the network, there is no incentive for the ISP to upgrade the backhaul. The network as a whole is limited by the difficult “last mile” problem. In order to progress infrastructure, one must take a holistic approach; it is insufficient to upgrade just one portion of the network. We refer to this paradox as network stagnation.

To address the network paradox problem, there are two ways to work around the limitation:

1. Work can be accomplished on the technology at the end points, increased line rate efficiency, and the use of digital signal processing, which will produce increased efficiency utilizing existing infrastructure.

2. Concentrate efforts on the weakest link. Google fiber was launched in 2012 to select cities to bring gigabit Internet connections to the home (2015). This deployment of fiber optic cabling infrastructure can handle much faster speeds now and accommodate faster speeds in the future without the need for new cabling. Most new subdivisions follow the axiom of "dig once." Utilities and telecommunication hookups are placed at the time of construction and theoretically not touched unless the need for repair exists. In the case of ISPs, dark fiber is put in place awaiting utilization. In the 1990s, the Clinton-Gore Administration spearheaded a "National Infrastructure Initiative" where the government subsidized the laying of dark fiber (Kahn, 1992) so that every school, home, office, library, public institution could be connected. This was the start of the Internet age. However, large publicly funded initiatives have languished since then. Widespread digital video streaming services have stressed these networks to their breaking points, forcing infrastructure upgrades or service changes. This same paradox is true on military networks when dealing with shipboard communications. The slow speed of legacy satellite systems is the weakest link.

A highly compressed HD video stream with a modern codec requires 7–10Mbit of bandwidth to view without degradation occurring. For legacy networks of 100Mbits, this would only allow 10 users viewing HD content simultaneously, before network saturation occurs and performance degrades. Costly network upgrades to infrastructure or sacrificing video quality must be implemented to facilitate viewing.

According to Statista, Netflix has a 36 percent share of peak downstream traffic in the U.S. (2015). With smartphones saturating the marketplace capable of filming and viewing HD content, network infrastructure will need the capacity to support users. Video on demand services, coupled with multiple people connected in typical households, require an increasing amount of bandwidth to support a myriad of capabilities that smartphones provide. According to YouTube, with over a billion users, people watch hundreds of millions of hours on YouTube every day and upload 300 hours of digital video each minute (2015). This explosion of readily available HD video content and the user demanded connectivity drives network infrastructure advances, as well as the desire for increased bandwidth, display resolutions, and computing power to access UHD 4k or even 8k content.

III. VIDEO CLOUD SYSTEM

HD video consumes more network and computational resources when compared to lower resolution video. Existing network capabilities, as well as legacy video editing systems, are insufficient to meet the bandwidth demand that accompanies HD content. Video traffic volume is larger than any other type of online traffic today, which is creating significant incentives to increase network capacity (Breiling et al., 2014). This research evaluates a portable video cloud solution allowing for multiple signal inputs, configurable workflows and new compression codecs to deliver content in support of various applications and operations.

A. O3B NETWORKS SATELLITE COMPONENT

1. Background

Many departments on U.S. naval vessels now have requirements for Internet connectivity as part of their normal, daily operations. There is also an increasing demand to share high-quality media both internally and with others. Yet, the bandwidth from legacy satellite systems currently available to naval vessels of all sizes is highly constrained. Specifically, it does not meet the needs of the PAOs afloat on large vessels, such as aircraft carriers, LHDs, and LHAs.

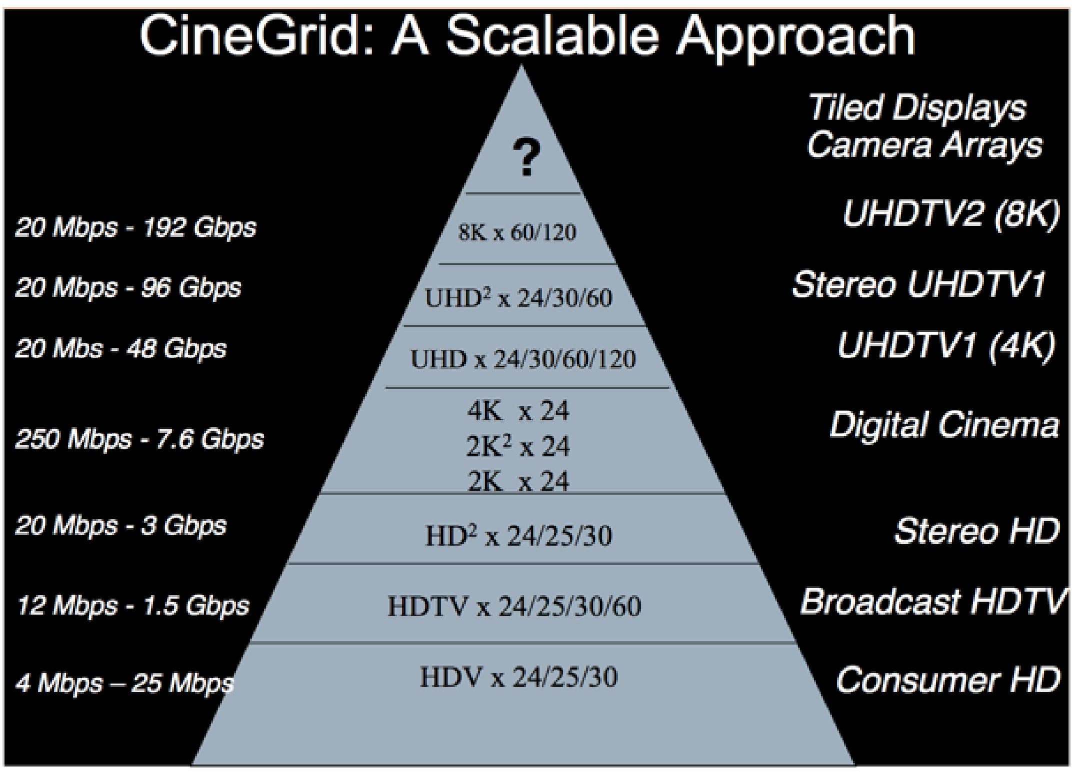
O3b Networks advertises network speeds well in excess of the current capabilities and sufficient to conduct file-transfers of large video files in HD, which can exceed many gigabytes in size. This capability is very attractive to PAOs tasked with collection and dissemination of “broadcast quality” video in support of operations, such as humanitarian assistance/disaster relief (HA/DR) and community relations.

Compared to current speeds, this seems to be excessive, but data rates for HD, UHD (4K) and even Super Hi-Res (8K) video can easily exceed this capacity in a single stream. Video has long been considered a bandwidth ‘hog’. Even compressed video, such as streaming video from Netflix, can quickly consume all available bandwidth. CineGrid, an international non-profit virtual research organization, focuses on the network use of

very high-quality media. Figure 13 illustrates the potential data rates for various formats of digital video.

Uncompressed 8K (7680x4320 pixels) at 60 frames per second far exceeds the capacity of even the fastest satellite network, and requires multiple 100 Gbps photonic networks for transport at 192 Gbps. Yet, 8K transmissions are now possible; Sharp Electronics announced in September 2015 that they would begin selling 8K-capable televisions in October 2015 (Keion, 2015). So, even the fastest satellite networks will be hard put to keep up. Advanced codec algorithms and compression can help, but the trend is clear: video is scaling and data rates are skyrocketing.

Figure 13. Various Video Data Rates



Source: Herr, L. (2010). Data rates for HD and emerging UHD formats [PowerPoint slides]. Retrieved from https://www.nitrd.gov/nitrdgroups/images/d/dc/CineGridMAGIC_77_2010_Herr2.pdf

Constantly evolving technology increases the ability to display higher resolution video through the means of monitors, projectors, and video recording equipment. As the general consumer market puts pressure on networks to deliver these ever-increasingly high-resolution formats, the U.S. Navy will benefit, if it can adopt these same technologies. Obviously high-resolution imagery and video would be of great use to many operational departments, such as combat operations, battle damage assessment, unmanned systems and others, but this thesis focuses solely on its use for public relations.

The ability to send high-resolution video from sea to shore at speeds that do not impinge on operations requirements, requires a different strategy than the usual use of GEO satellites. The O3b Networks satellite system has the potential to contribute to the quality of life of naval personnel onboard as the expected extra capacity provides the ability to connect with family over social media, connect sailors to official Navy websites, or provide a robust Internet connection for any other bandwidth intensive applications.

Although geostationary satellites are evolving at a relatively fast pace, a MEO satellite has the advantage of being only a quarter of the distance from the earth. This allows for a stronger signal from a smaller satellite and faster round-trip time leading to low latency. Using the MEO positioning technique, multiple satellites are required to be in orbit in order to keep a constant connection. This is in contrast to GEO satellites placed in a permanent position above the earth and are able to provide service to only a portion of earth. MEO orbital slot selection adds complexity due to the need for multiple antennas for each terminal to maintain a constant connection. The required two MEO satellite terminals use a make-before-break method, which establishes a connection to the other terminal in order to track the satellite as it moves across the sky with no service interruption.

Low latency is a significant advantage of using a MEO satellite to connect afloat activities with others. GEO satellites have a high latency because they are approximately 36,000 km above the earth's equator. Even at the speed of light, these vast distances contribute to significant latency, which affects quality of service (longer latencies typically result in higher packet loss for TCP/IP networks). At this distance, latency

measures 500–600 ms compared to 120–150 ms for an 8,000 km MEO orbit. Low or moderately low latency typically does not affect file transfers other than slowing the transfer (no data are lost), but for live-streaming video and Voice Over Internet Protocol (VOIP) the delay is quite noticeable and deleterious.

2. Hardware and Architecture

O3b Networks has a myriad of terminals and hardware configurations to meet customer demands. This research concentrates on the use of smaller, mobile terminals to support PAO requirements in remote locations.

a. Hardware

Terminals used consist of three different classes: a ground based version, a mobile version, and a maritime version. Ground based terminal common sizes are 1.8 m, 2.4 m, and 4.5 m. In general, the larger the satellite terminal, the higher the throughput, especially regarding upload speeds. Larger terminal configurations require more power than smaller systems. 1.2 m and 2.2 m are the most common sizes of the maritime terminals. There are other less common configurations that use smaller terminals for ship applications, as well as much larger terminals for ground stations. The mobile terminal solution is a smaller .85 m antenna, which can be set up in less than 90 minutes. Both maritime and mobile systems have the necessary auto-tracking capability required to accomplish satellite tracking to maintain connection.

b. Architecture

O3b Networks is a Ka band satellite system composed of 12 satellites. Ka band operates at 26.5–40 giga-hertz (GHz) and is a desirable portion of the electromagnetic (EM) spectrum, since it has a vast amount of bandwidth available for use when compared to lower frequencies. Each satellite is a relatively small 700 kg when compared to typical GEO satellites. This gives the ability to launch multiple satellites into orbit simultaneously. The multi-satellite configuration at launch is shown in Figure 14.

Figure 14. O3b Networks Multi-Satellite Configuration

Source: http://spaceflightnow.com/2014/12/17/photos-o3b-satellites-prepared-for-soyuz-launch/

For any satellite terminal system to have optimal performance onboard a ship, it must be mounted on the highest point possible to prevent view obstruction. Retrofitting these O3b Networks terminals on current naval ships will prove to be a significant issue due to the lack of available elevated exterior deck space. Although placement of these terminals will be in the best possible location, there will still be blockage zones from ship equipment depending on the azimuth and elevation of the antenna and ship's movement. Unlike a ground station, a ship can have any heading, therefore any possible occlusion that can happen, will happen. Rain fade and the RF environment are also factors that will potentially degrade data transmission. Constant ship movement as well as each transition from one satellite to another requires the antenna to be placed upon a gimbal to maintain line of sight contact with the satellite in use. These are well-known considerations and not unique to any particular satellite system.

3. Operational Capability

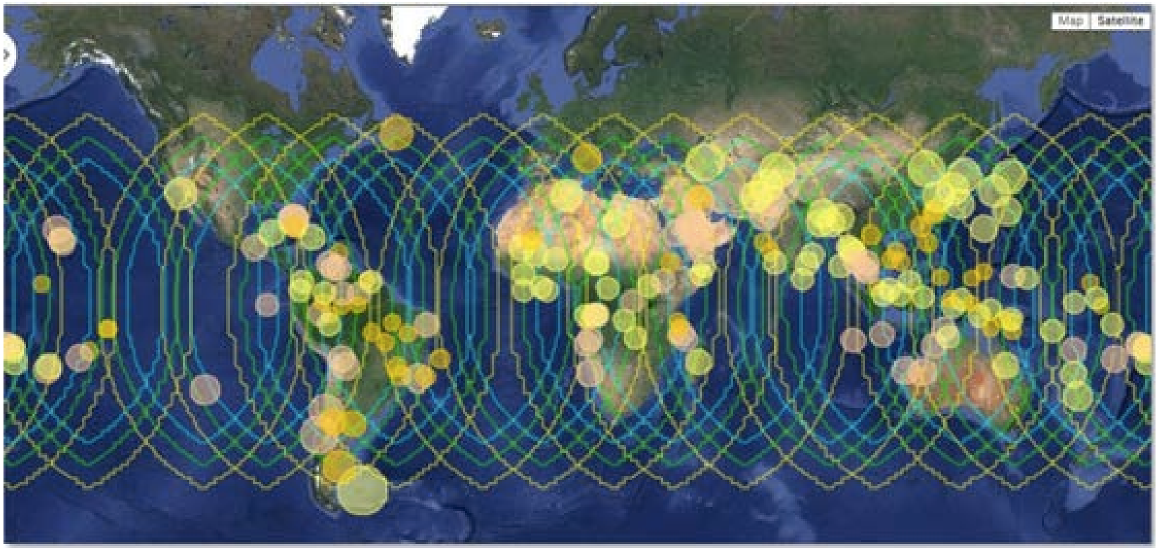
Each of the 12 O3b Networks satellites use 12 steerable Ka band transponders that have a 700 km useful diameter with two dedicated for gateway access. (Technology, n.d.). Figure 15 displays the 12 total transponders. Each transponder is capable of speeds up to 1.6 Gbps including a maximum of 84 Gbps for an eight-satellite constellation (Technology, n.d.).

Figure 15. O3b Networks Satellite Transponder Display

Source: http://spaceflightnow.com/2014/12/17/photos-o3b-satellites-prepared-for-soyuz-launch/

The steerable beams have the ability to be placed anywhere within 45 degrees north or south of the equator to provide standard service, or within 62 degrees north or south for limited service (Technology, n.d.). This limited service area is sometimes called "extended service" and is not guaranteed coverage. Satellite acquisition at higher latitude locations have low look angles and atmospheric attenuation hindering the signal, resulting in intermittent connectivity or a reduction in performance. Figure 16 shows the current footprint of O3b Networks satellite constellation at various look angles.

Figure 16. O3b Networks Satellite Footprint at Various Look Angles



Source: K. Mentasti, personal communication, November 3, 2015.

B. NPS VIDEO CLOUD SYSTEM

1. Introduction

There are many similarities to Satellite News Gathering (SNG) in our approach, but traditional SNG does not support the ingestion of media from a very wide array of devices now capable of generating a broadcast quality signal, nor does it allow for future capabilities, such as 4K (3840x2160 30/60pfs) at higher spatial and temporal resolutions. Our approach allows for a diversity of signal inputs, configurable workflows, the adoption of new compression codecs and emerging transport streams, and is based on media delivery over IP.

Our man portable system can operate independently, ingesting content, managing content, and fulfilling requests (video-on-demand) in multiple, standards-based formats in real time (no waiting for lengthy transcoding). At the heart of the server is NTT America's SHS-XMS media server system, powered by iVisto (Internet Video Studio for HDTV production). According to NTT, the system integrates into a network and implements transport in real-time, allows for content storage, and uncompressed HD

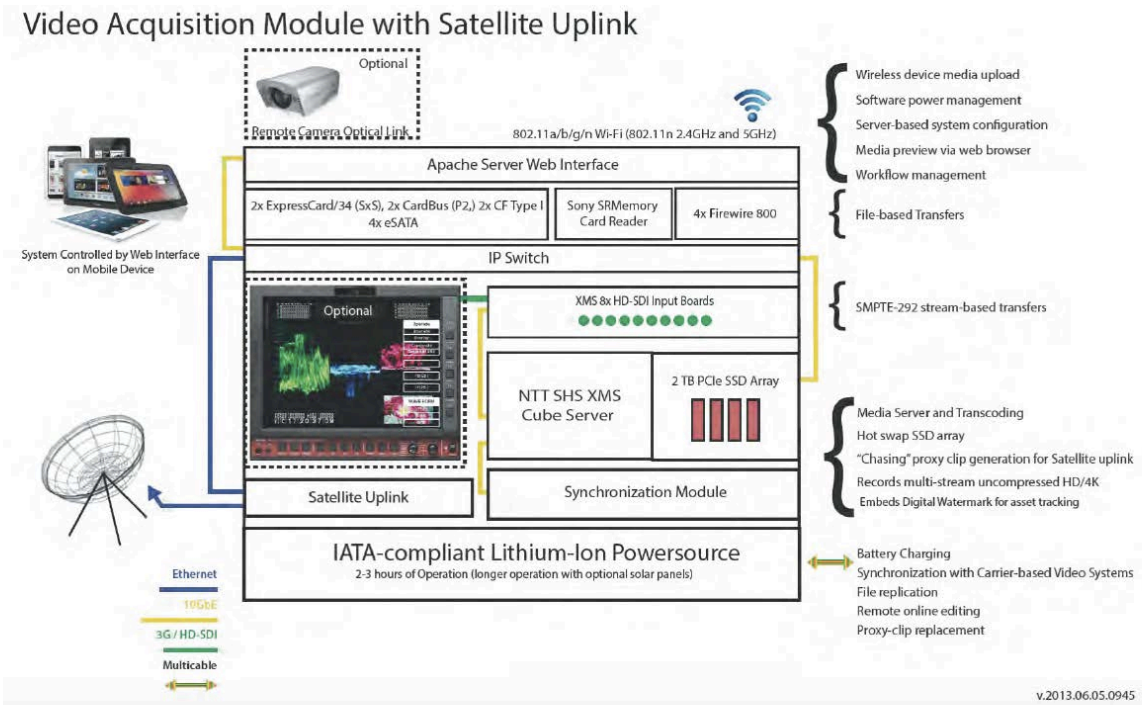
content transportation over an IP network with speeds of 1.5Gbps (The i-Visto Internet HDTV video studio system, n.d.).

Typically, these IP-based video architectures are located in a studio or production center, but here, they form the backplane of the video acquisition module (VAM). The VAM is capable of joining a cloud-based video system over existing and future networks, leveraging a unique capability of network transport over IP to enable local workflows. At a remote site, a simple workflow allows for a proxy clip to be sent over a satellite link in support of online editing at a stand-alone video production lab using widely accepted non-linear editing (NLE) tools, or at shore-based studio facilities with all the production capabilities of Defense Video and Imagery Distribution System (DVIDS).

2. Components

The VAM is a self-contained, one or two-man portable video acquisition module. Figure 17 depicts the Video Acquisition Module Block Diagram and illustrates the basic system design. The VAM supports file-based workflows (e.g., transfer of still images via compact flash or video transfers by Firewire (400/800) and ingest of real-time transport streams such as HD serial data interface (HD-SDI) (SMPTE-292M/SMPTE-424M). It also supports media ingest through web uploads from mobile devices and laptops via embedded WiFi and an Apache Server running web services.

Figure 17. Video Acquisition Module Block Diagram



Source: J. Weekley, personal communication, July 12, 2013.

a. *4U Mini-XMS Server*

A 4U solid-state computer physically configured to minimize weight and dimensions was chosen (cube PC running STIG'd versions of Linux). It is dedicated to file I/O for file-based workflows using Firewire, portable media and web-uploads to an Apache Web Server Interface. It has a dedicated Solid State Drive (SSD) array to accept file-based media transfers. This general purpose PC also runs web-services for system configuration management, media previews and workflow management. It enables rapidly reconfigurable workflows based on file type, customer requirements and smart decisions about when and where computation occurs. The server also hosts sophisticated power management software that maximizes battery life by turning on services only when workflows require them. The solid state architecture, such as SSD and Application Specific Integrated Circuit (ASIC) boards for real-time transcoding services, allows for sophisticated software control of system components with fast initialization times

required in contrast to traditional hard disk drives (HDD) (non-solid state) or purely software based systems.

Signals acquired by HD-SDI bit streams are recorded as bit streams to the SSD Array memory in bit order. This virtualizes the camera interface and allows later processing and synchronization workflows. ASIC-based transcoding services is run simultaneously with extremely low latencies (less than 1 frame) and the subsequent transport stream sent to the Satellite Uplink module over IP. Thus, the receiving station(s) have immediate access, if required. For file-based transfers, a combination of software and hardware transcoders transforms the file-based media into appropriate transport streams for satellite uplink and downstream use in NLE workflows. All media is held in the VAM as both light weight proxy clips for local preview and transmission, as well as uncompressed video or native formats from file-based transfers and web uploads.

Though the VAM can operate for at least 2 hours on battery power, media written to SSD arrays can represent many more hours of content. Total media carrying capacity varies depending on media formats and attached drives (portable media left in the VAM will act as memory expansion). Bit-stream recording of HD-SDI signals to the SSD Array associated with the SHS XMS iVisto system is approximately 1.5Gbps. A 2TB SSD array holds approximately 3 hours of uncompressed video. To minimize complexity, file-based transforms for uplink are all to be transcoded to an appropriate canonical format. Figures 18, 19, and 20 show the rear and side 4U server views, as well as the diversity of signal input options available.

Figure 18. 4U Mini-XMS Server Side View

Figure 19. 4U Mini-XMS Server Rear View

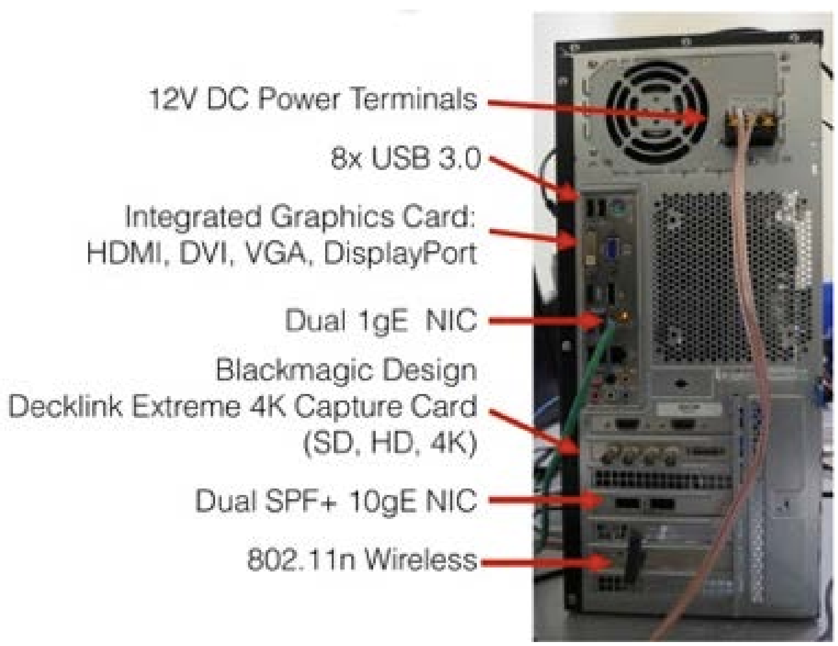
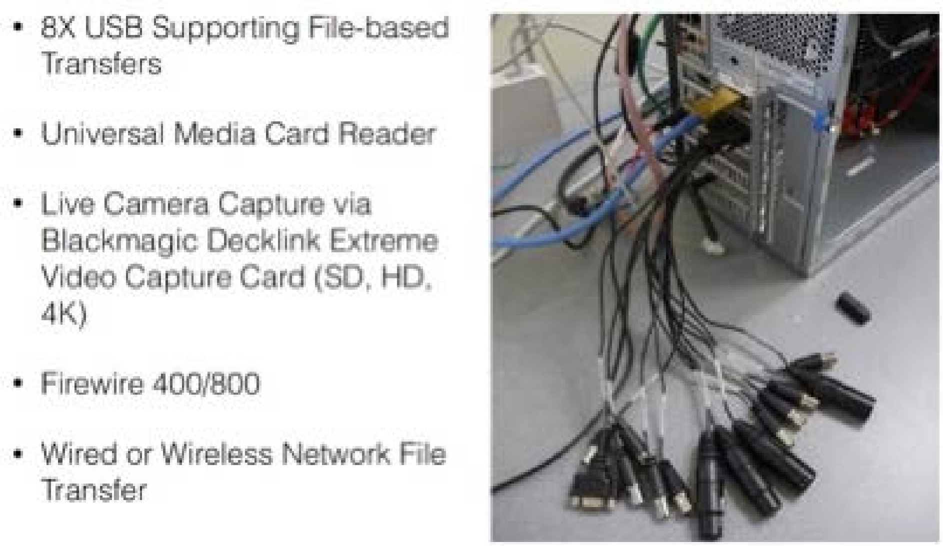


Figure 20. 4U Mini-XMS Server Inputs

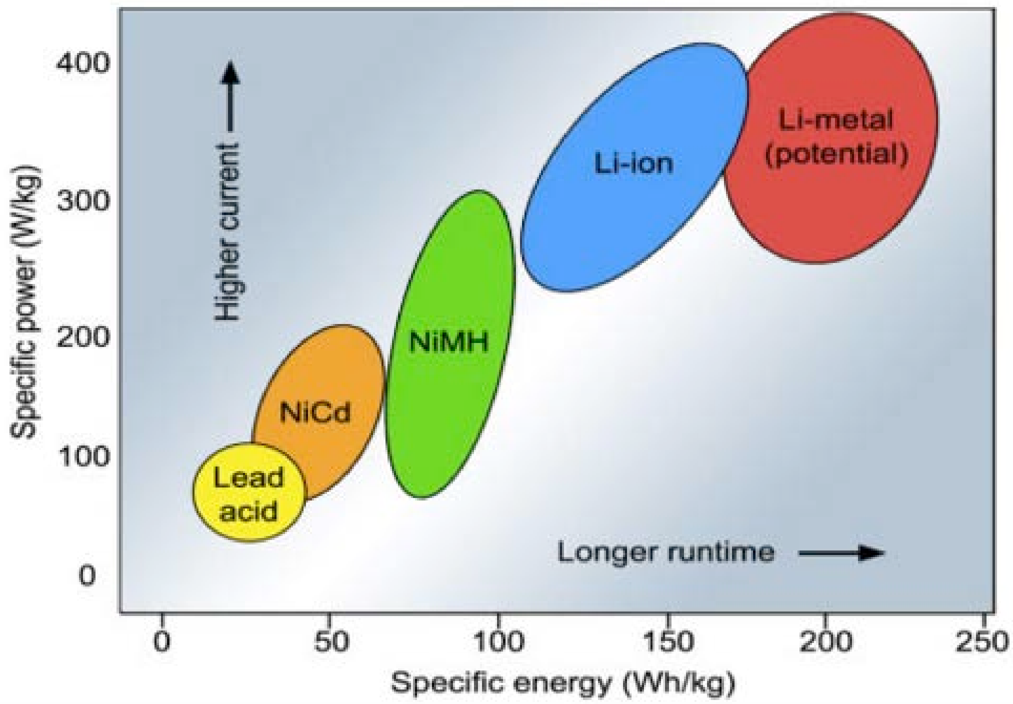


b. 4U Mini-XMS Mobile Power Source

The field-deployable 4U server demands a considerable amount of power from a battery source for normal operation in remote locations. Two different battery types were tested for different scenarios: Lithium-Ion (Li-ion) and Nickel Metal Hydride (NiMH). Charging of these batteries is accomplished through any means available including solar and generator power.

NiMH batteries are an older technology but are an improvement upon the similar but older Nickel cadmium (Ni-Cd) battery technology. They have high energy density but also high self-discharge which limits their readiness and effectiveness if left uncharged for a period of time (Ferreira, Garde, Fulli, Kling, & Lopes, 2013). Li-ion battery technology is reliable and proven to be extremely efficient while the discharge rate is low when compared to other similar technologies (Ferreira et al., 2013). This makes Li-ion the most attractive option for field use. Figure 21 shows the energy density comparison.

Figure 21. A Comparison of Energy Density of Various Small Sealed Battery Systems



Source: Global Battery Markets Information—Battery University. (2015). Retrieved from http://batteryuniversity.com/learn/article/global_battery_markets

A significant disadvantage of using the more efficient Li-ion batteries is that they have a potential for thermal runaway, which can cause an explosion. There are many restrictions when they are transported on an aircraft. The International Air Transportation Association (IATA) has multiple regulations against transporting Li-ion batteries on airliners. According to IATA, any Li-ion battery over 100 Wh is subject to strict limitations. For this reason, the less efficient NiMH batteries are a viable alternative for air travel until policies change. Additionally, there are also a myriad of local regulations that govern the transportation of Li-ion batteries. Misunderstanding of the controlling regulations and lack of training for inspectors and border security personnel can result in delays and equipment seizures during transportation on commercial airlines, especially for international transportation.

(1) Proposed Solution for the Field-deployable 4U Server

The North Atlantic Treaty Organization (NATO) approved battery enclosure houses two battery banks each composed of three batteries, which can be composed of NiMH or Li-ion. The banks can be set up to operate in series at 28.8 Volts Direct Current (VDC) or parallel at 14.4 VDC. Since this is commercial equipment, parallel at 14.4 VDC is what was required. The total energy with all batteries installed is approximately 1,200 Wh (Li-ion) and 800 Wh (NiMH). The DC power unit of the 4U server requires 12 VDC at 48 amps. Figure 22 shows the mobile power supply enclosure.

Figure 22. 6-Pack Portable Charging System

Source: Bren-Tronics. (2013). 6-pack portable power system operation manual. Retrieved from http://www.bren-tronics.com/bte-70791a-t1b.html

Special consideration should be given to the operational parameters of both the server and the batteries, as well as the two components working together. The batteries have an operational temperature range of 20°C to 60°C (-4°F to 140°F). Operating the batteries outside of this range will cause the batteries to fail or at the very least operate suboptimally. The operating temperature for the SuperMicro mid-tower 4U server is

10°C to 35°C (50°F to 95°F). When outside temperatures exceed 35°C, even though the batteries will continue to provide power, the server may experience faults.

3. Mini-XMS Compression Codecs

Since content delivery will be via satellite, it is important to apply advanced compression and media transport stream protocols. Even in the simplest design, where VAM synchronizes upon return, we wish to employ these advanced techniques. Current, widely implemented codecs such as H.264 and transport streams such as MPEG-2TS are less relevant, as signals arriving at the Shipboard Video Server (SVS) will be demuxed (decoded) exclusively from the VAM data stream. Therefore, emerging standards-based advanced codecs and transport streams, not widely adopted yet, but highly advantageous, can be employed. As long as ASIC boards at each tier can decode the data stream, great efficiencies can be achieved by our system and still allow for better-than-broadcast full motion video (FMV) to be acquired and distributed.

The SHS-XMS system embedded records uncompressed HDTV up to 4K (3840x2160 at 60 progressive frames per second). ASIC boards simultaneously transcode this signal to H.265 or MMT for down-stream delivery. But this transcode is non-destructive and the 4U Mini-XMS server is capable of recording and storing the uncompressed bit stream as SMPTE-292M or SMPTE-424M, or in a suitable interchange format such as Apple’s ProRes 422/4444, allowing for the future application of improved codecs and transport protocols.

C. SUMMARY

In this chapter, O3b Networks satellite hardware and architecture were discussed for use with our field-deployable video cloud solution. Next, the 4U Mini-XMS server design and hardware specifications were outlined for use with this research, showing hardware robustness and server efficiency are crucial with regard to design. As HD and UHD video consume resources, the need for increased computational performance and bandwidth to handle content delivery was addressed. Furthermore, detailed requirements

for the mobile power source were described and optimal battery configurations were identified to meet server demands for the field-deployable video cloud solution.

IV. IMPLEMENTATION AND EVALUATION

Within this chapter, we explore the use of our 4U mini-xms server in various digital video scenarios and evaluate the O3b Networks .85m terminal for use with the NPS Field-Deployable Video Cloud Solution. Satellite terminal evaluation was conducted at Marine Corps Tactical Systems Support Activity (MCTSSA) located at Camp Pendleton, CA, and 4U mini-xms server testing was conducted in the NPS Digital Video Lab located in Monterey, CA.

A. SYSTEM EVALUATION SETUP

Our evaluation is based on the following engineering objectives:

- Fixed, but modular physical configuration of the 4U mobile video content server with communications and file input/output (I/O) using standard protocols
- System should have a minimum of 15 dedicated inputs across three common media ingest workflows: 3G/HD-SDI (SMPTE-424M/SMPTE-292M); file-based uploads using portable media (e.g., camera hard drives, flash media, Sony memory stick) and Firewire/universal serial bus (USB); and many simultaneous web-uploads via embedded video portal for mobile devices
- IATA-compliant batteries and with optional alternative power (e.g., advanced solar charger, fuel cell)
- Minimum of 3 hours of run time on batteries
- Man-portable by one or two-man teams
- Transmit and receive no less than 1MB/s, including overhead, using current compression codecs and transport streams (e.g., H.264 and MPEG-2TS), as well as emerging ultra-efficient codecs and transport streams (e.g., H.265 and MMT), maintaining better-than-broadcast quality signal throughout transmission
- Robust workflow management for real-time shot selection, editorial and immediate release, as well as metadata preservation and versioning for long-tail fulfillment
- Selectively operable on KU, KA and X bands, but also operate compatibly with emerging SATCOM capabilities

- Air-transportable by commercial aircraft for Defense Security Cooperation Agency (DSCA) and U.S. Navy C-2 Greyhound: compliant with IATA checked baggage rules
- Local and remote media previews for easy shot selection and editorial decision-making
- Self pointing or auto acquisition of satellites
- High operational availability and easy configuration management via common web browsers
- Low maintenance requirements: solid-state design, sealed against dust and moisture, shock-resistant

The following sections describe both the satellite component and the server component of the NPS field-deployable video cloud solution and how they relate to our evaluation.

1. Satellite Component

a. AVL .85 m Terminal

Of the many different satellite antenna configurations available for use, our evaluation used the .85 m Tracking Fly Away Antenna System (TFAAS) shown in Figure 23. Other satellite configurations utilize a 1.0 m or 1.2 m reflector panel for increased performance, but the .85 m terminal was the optimal combination of size and performance for man-portable use. The TFAAS uses a slew drive positioning system with an elevation over azimuth worm gear design, enabling a one-button auto-acquisition capability designed for reliability, durability, and minimal maintenance for the user. The electric motor operates on 28 VDC and antenna slewing occurs at a maximum rate of 4 degrees per second. TFAAS Rx/Tx feeds are a 2-port Ka-Band configuration capable of circular or linear polarization. The Ka-Band Rx frequency range is 17.85–19.27 GHz and the Tx frequency range is 27.65–29.07 GHz.

Figure 23. Tracking Fly Away Antenna System Terminals

The TFAAS came with everything required for satellite acquisition, signal routing, and network connectivity. It requires an external power source for operation that was provided by MCTSSA support personnel. Total setup time for the system should take less than 90 minutes, including a 40-minute auto acquisition period. The system is capable of operating in 45 mph winds with gusts of 60 mph and temperatures ranging from -22°–125° F.

TFAAS is comprised of eight rugged pelican cases that house various components. These cases provide the security and safety of the equipment during transit and meet the specifications for C-2 (Greyhound) airlift requirements. Each case weight adheres to our engineering objective for man-portability. Figure 24 depicts a typical configuration of TFAAS ready for customer delivery.

Figure 24. TFAAS Factory Packout

Once unpacked and set up for use, TFAAS was housed in two cube pelican cases. These contained modems, switches and various network components to provide user connectivity. A detailed bill of materials (BOM) for the TFAAS is available in Appendix B. Figure 25 shows the satellite network components required for operation.

Figure 25. TFAAS Operational Components

b. O3b Networks Satellite Specifications

There are 12 satellites in the First Generation O3b Constellation, with nine active satellites in use and three spare satellites in orbit for redundancy or rapid satellite repositioning. The satellite orbital period is approximately five hours and moves from east to west. This equates to approximately four orbits a day and new satellite acquisition occurred every 40 min seamlessly between the two terminals. Satellite evaluation took place near 33 degrees N latitude at Marine Corps Base Camp Pendleton, and based on antenna positioning, no blockage zones were present during the evaluation. This latitude resides well within the published coverage footprints that O3b Networks advertises.

c. O3b Networks Gateways

According to O3b Networks, nine teleports (gateways) are utilized for connectivity and routing decisions for 12 satellites, including nine active satellites in the First Generation Constellation (J. Shaw, personal communication, November 3, 2015). The satellite evaluation for this thesis used the gateway located at Vernon, Texas and support for the site is provided by Level 3. Figure 26 shows installed O3b Networks antennas located at the Vernon data gateway site. O3b Networks gateways are located in areas where the Internet backbone resides (Technology, n.d.).

Figure 26. Vernon O3b Networks Gateway

Source: Paciaroni, J. (2014). *O3b Teleports Information Booklet*.

2. 4U Mini-XMS Server

A Supermicro 4U rack mountable tower form factor was chosen to meet the size constraints outlined in engineering objectives and can be transported via pelican case for ruggedness and durability. The microserver housing is sealed to help minimize dust and dirt intrusion while providing expansion slots for future upgrades if desired.

a. Mobile Power Supply

The battery types selected to power the 4U Mini-XMS server were NiMH and Li-ion. While the Li-ion batteries can be charged in their cube housing via an external cable, the NiMH batteries require an additional piece of hardware to facilitate charging. Figure 27 shows the Bren-Tronics Soldier Portable Charger (SPC) used for NiMH battery charging conducted in the NPS digital video lab. According to the Bren-Tronics (2013), the SPC, national stock number (NSN) 6130–01-495-2839, requires a 90–260 volts alternating current (VAC) or 22–28 VDC input to charge up to eight NiMH batteries using an incremental cycling charging approach with an light emitting diode (LED) readout displaying battery status. The Bren-Tronics user manual states that the system automatically charges up to eight batteries in approximately eight hours, depending on the battery type and state of the charge (Bren-Tronics, 2013).

Figure 27. Bren-Tronics Soldier Portable Charger

Li-ion charging was accomplished using the Bren-Tronics 6-Pack Portable Power System. The 6-Pack requires 90–264 VAC to charge six batteries housed within the enclosure. According to the Bren-Tronics 6-Pack user manual, only U.S. DOD approved BB-2590/U batteries are recommended for charging with this device (Bren-Tronics, 2013). The batteries utilized for this research are BB-2590/U DOD approved Li-ion and NiMH. The user manual goes on to state that charge times assume fully-discharged batteries prior to charging and no load applied during charging (2013). Approximate charging time for six Li-ion batteries is 11–16 hours. Figure 28 shows the Bren-Tronics 6-Pack unit with our Li-ion battery configuration.

Figure 28. Bren-Tronics 6-Pack Portable Charging System

b. *Memory Requirements*

As discussed in Chapter 3, the 4U Mini-XMS server requires HDD performance to exceed average capabilities of traditional HDDs to meet the demand of real-time transcoding services and sophisticated software control of various system components. A third party vendor, Aspen Systems, was brought onboard to verify system performance and server build specifications to meet our engineering requirements. Aspen systems played a vital role in troubleshooting and resolving various server component issues during construction and system evaluation.

c. *Media Ingestion*

The Mini-XMS server is capable of providing connectivity via standard wired gigabit Ethernet, 10GE, 802.11, Universal Card Reader functionality and USB supported file-based transfers, as well as the connections provided from the Blackmagic Decklink

Extreme Video Capture Card. These connection options provide sufficient avenues for users to ingest video content and choose desired delivery format. This research and evaluation was based on the Mini-XMS server being networked for maximum user availability and functionality during operations in remote locations.

Our ingestion experiments were simulated with numerous accounts uploading content simultaneously to the 4U Mini-XMS server. While file-based ingestion was available, our evaluation used LAN connectivity and virtual private network (VPN) connections to upload content via wireless and wired connections. Streaming content was ingested via 3G-SDI from our GY-HM750 JVC HD studio camera to the Blackmagic video capture card. Figure 29 shows the streaming content media ingestion evaluation setup.

Figure 29. Digital Video Streaming Test Setup

d. Compression and Transcoding

After content ingestion into the XMS side of the media server, users have the ability to choose the desired format for transcoding, or users can transport the uncompressed video content stream over the network. The transcoding process is non-destructive and content is stored on the SSD array for future use. During server construction, several collaborative efforts using NTT proprietary Meeting Plaza software took place between NTT engineers to configure and update NTT America's SHS-XMS media server system and ViaPlatz software Graphical User Interface (GUI). These collaborative efforts allowed for UHD content up to 4k to be utilized by our system.

Several pre-loaded options and custom transcoding formats are available for use with our system. Figure 30 shows multiple users transcoding content into various delivery formats.

Figure 30. Video Transcoding Processing Status

View Transcoding Status

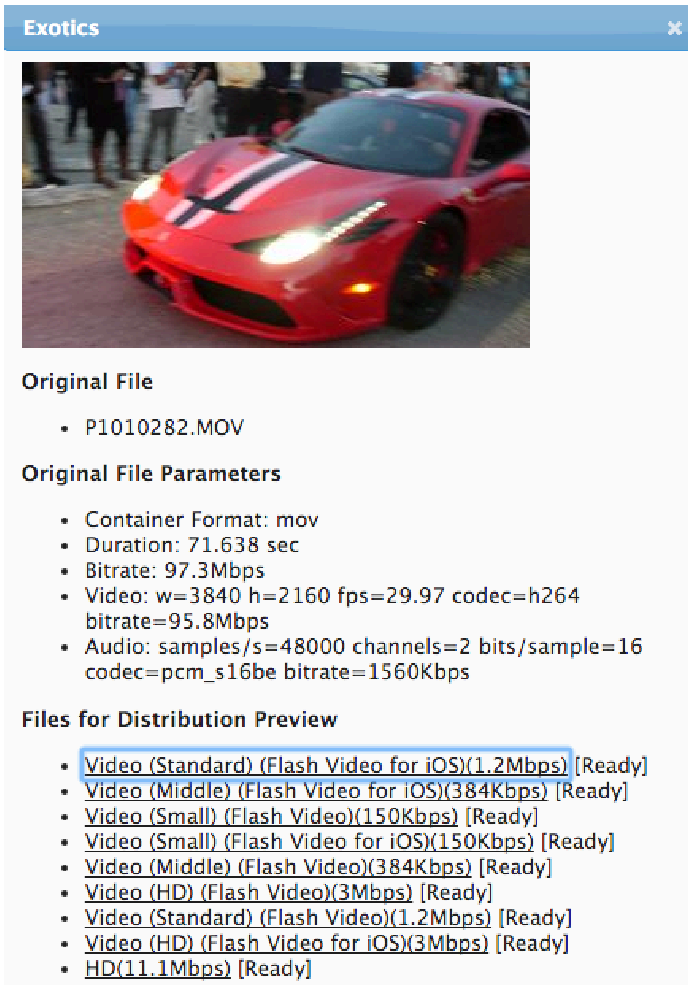
Materials in transcoding

Material Name	Format	Bitrate	Task Status	File exists?	Current Transcoding Status	Task ID
Exotics 3	mp4	for SceneEditor	PENDING	False	Waiting to start (Wed Nov 4 02:26:17 2015)	0daa3467-18ea-4e49-953d-cb12b97da330
Exotics 3	flv	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:17 2015)	825cc719-4a57-4647-ac6c-d53b23b4f0b3
Exotics 3	mp4	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:17 2015)	c3361c43-433e-477b-ba86-6f51410dc9d8
Exotics 3	flv	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:17 2015)	1e66914c-f868-4e9a-a8ec-03fc79d5b3fd
Exotics 3	mp4	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:17 2015)	2403b974-ae48-40b2-b817-9fb43a1d1bb6
Exotics 3	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:17 2015)	2ec19bd0-6e7a-4693-ba6a-8a1dca48e648
Exotics 3	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:17 2015)	8300f5d1-08d7-4730-b79b-f4d1edcb8453
Exotics 3	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:18 2015)	c4d11087-70ef-4d2e-bf46-d0bc27b1447f
Exotics 3	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:18 2015)	3e8be83f-6d73-4df1-a1e3-9d2cfe307dc0
Exotics 3	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 02:26:18 2015)	20d3d012-d468-4342-b9b1-f87ce451e773
Grandpa and Grandma 2	flv	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	60eefd07-ffbd-47ba-8b42-34220db5aa43
Grandpa and Grandma 2	mp4	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	f9b639b2-2926-4f7d-a012-89a00cf03f43
Grandpa and Grandma 2	flv	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	2ac8edb7-f7c0-46ec-8c9d-fa2bcaf351f4
Grandpa and Grandma 2	mp4	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	50bc91d8-b921-4c4d-b870-64b2112413e3
Grandpa and Grandma 2	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	7dc7b2af-4aea-4900-b4a5-86559931edec
Grandpa and Grandma 2	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	6fe9d2b3-6333-4d07-bbbe-76a8fa858a41
Grandpa and Grandma 2	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	2b844d15-cf22-4810-8921-fb0677b4e475
Grandpa and Grandma 2	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	64e477ce-123a-405b-8daf-7e34da94db82
Grandpa and Grandma 2	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	0c9c1c6e-79ae-49d1-9ee3-63b948f32c97
Grandpa and Grandma 2	mp4	for SceneEditor	PENDING	False	Waiting to start (Wed Nov 4 03:07:14 2015)	d1203d01-cd05-490c-aedd-857b86de0dd8
Jack Eating 2	mp4	for SceneEditor	PENDING	False	Waiting to start (Wed Nov 4 03:16:46 2015)	9045b426-eb5a-4274-baf4-ebdc57f1f27f
Jack Eating 2	flv	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:46 2015)	06de6931-b632-4f41-bbc2-944e3eb4cf24
Jack Eating 2	mp4	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	26e1c911-9fc0-4a0b-a358-143df9481ba5
Jack Eating 2	flv	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	550784f0-0020-44da-8f5b-3e4e830293f3
Jack Eating 2	mp4	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	6c1edb59-98b1-451f-8e2b-9a7f60990cc1
Jack Eating 2	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	ca9abca9-35ca-40d6-8f19-2849f29624ae
Jack Eating 2	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	41b07a84-fa16-4835-bcb0-5da9ba958fc2
Jack Eating 2	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	b8518c3f-2bd6-497d-9022-357867c6957a
Jack Eating 2	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	96a4ec5c-289b-4155-9f51-ee6c26f8bacf
Jack Eating 2	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	f21acdcf-7f45-45fd-94b2-0267fb4fcf25
bike 2	mp4	for SceneEditor	PENDING	False	Waiting to start (Wed Nov 4 03:40:01 2015)	c7740ce1-14ea-4ace-902a-db34f7fb5997
bike 2	flv	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:40:01 2015)	de6d88f7-f078-42ab-bf2f-ba226ddfdd12
bike 2	mp4	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:40:01 2015)	8d423075-62ab-4a82-a04b-8902f700d4c2
bike 2	flv	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:40:01 2015)	c67d4afc-d38d-4e03-a9e6-14f82180812f

Close

The compression algorithm utilized for our evaluation was the H.264 codec. This widely implemented and accepted codec was selected by NTT engineers for use with their software. Figure 31 shows 4k video content recorded at 4K30 fps, which was compressed and transcoded for distribution via H.264 codec with an audio and video combined bitrate of 97.3 Mbps.

Figure 31. 4k30 fps Post Transcoding Process



B. SYSTEM EVALUATION FINDINGS

1. Satellite

The O3b satellite architecture for this evaluation is described in Figure 32. While other gateways were available for use, the Vernon gateway was utilized for this evaluation.

Figure 32. MCTSSA O3b Satellite Evaluation Topology

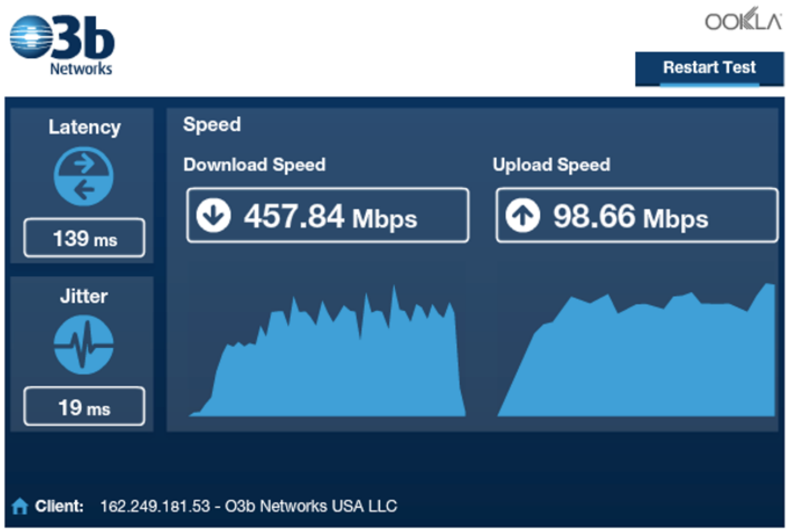
Source: J. Shaw. (2015). O3b Networks Government Test & Evaluation Demonstrations Update.

a. *Performance*

The O3b Networks Satellite evaluation took place at Marine Corps Base Camp Pendleton, San Diego, with clear sky and no obstructions to degrade satellite performance. Both satellite terminals were operational for the duration of the evaluation. A commercial off the shelf (COTS) Netgear Nighthawk X6 AC3200 Triband Gigabit Wi-Fi router was used to provide wireless connectivity from O3b Networks equipment to a MacBook Air laptop computer to capture data for system evaluation.

Throughput speed tests to the Vernon, TX O3b Networks gateway revealed an average download speed of 443.20 Mbps, and an average upload speed of 98.31 Mbps. This greatly exceeded the research requirements of 50 Mbps total throughput put in place by ONR. In our tests, latency averaged 138.25 ms and jitter averaged 2.17 ms (Figures 34 and 35). An example of the Vernon speed test results is shown in Figure 33. Speed tests to the commercial server speedtest.net revealed a much slower throughput with an average of 21.33 Mbps download and 28 Mbps upload.

Figure 33. O3b Networks Vernon Speed Test



Last Result:
Download Speed: **457836** kbps (57229.5 KB/sec transfer rate)
Upload Speed: **98662** kbps (12332.8 KB/sec transfer rate)
Latency: **139** ms
Jitter: **19** ms
9/17/2015, 2:43:03 PM

Three satellite handoffs occurred during this duration and are represented by the noticeable increases in latency and jitter on the graph.

Figure 34. O3b Networks Satellite Latency versus Time

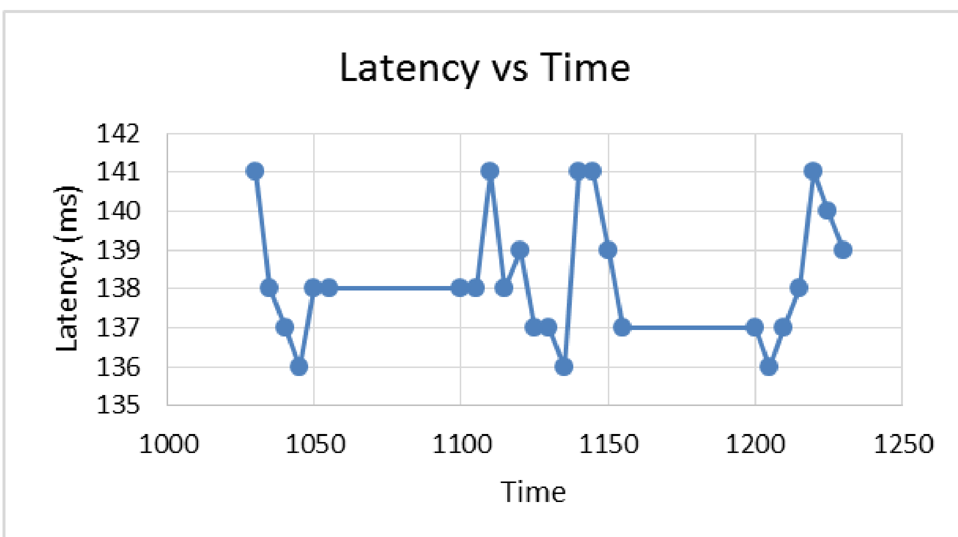
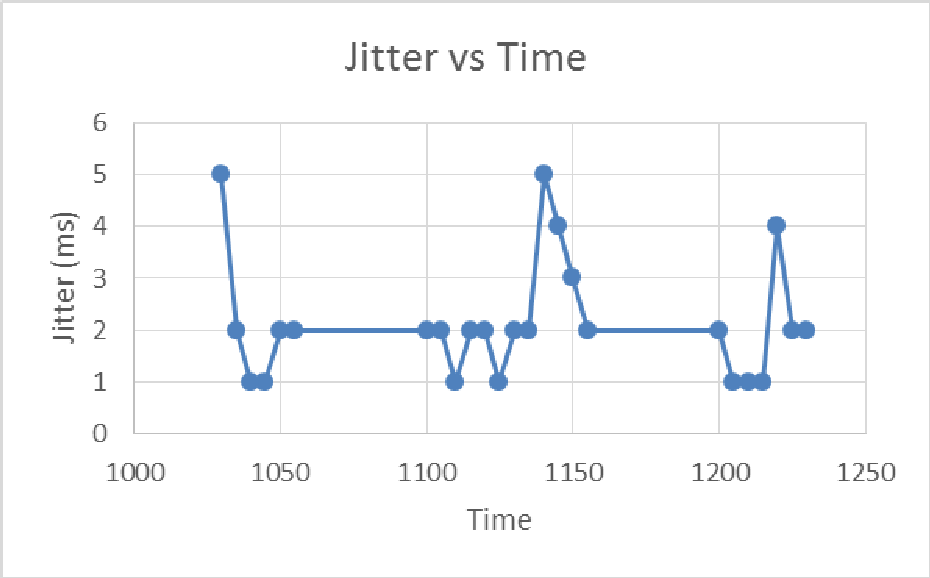
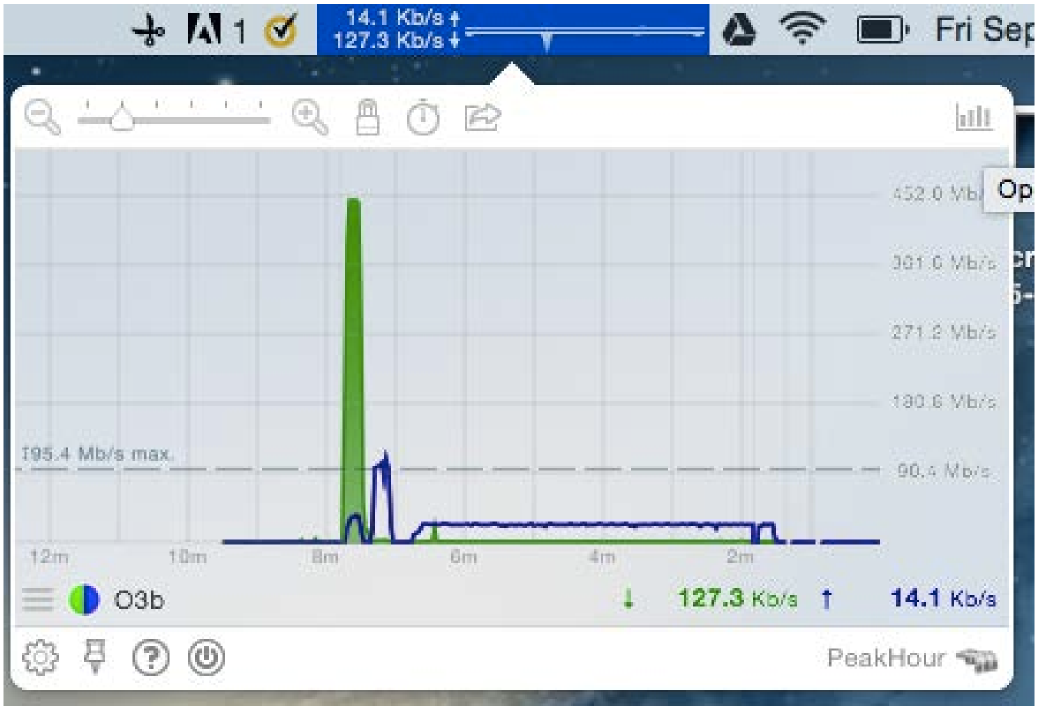


Figure 35. O3b Networks Satellite Jitter versus Time



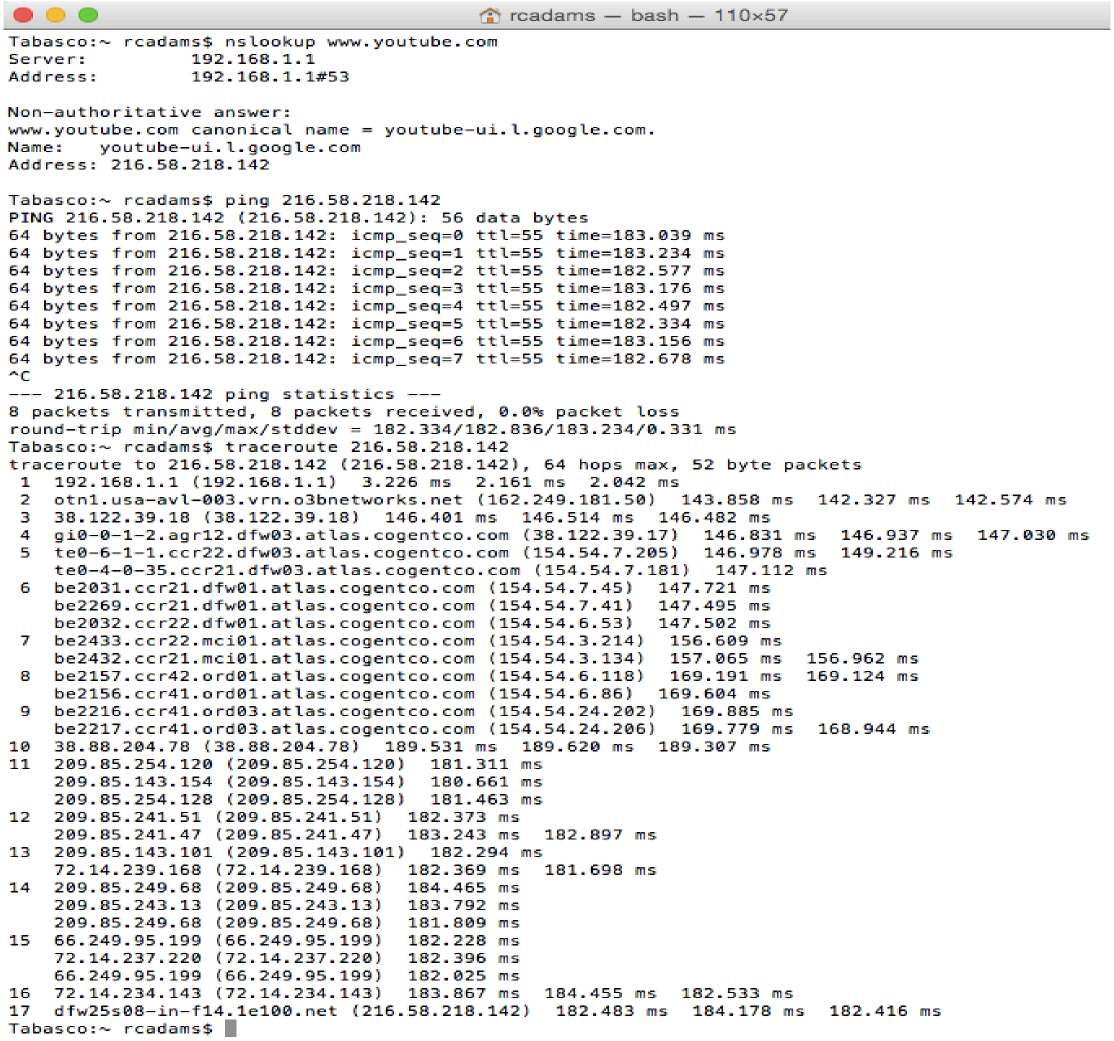
A network monitor captured network throughput during various applications to include a 1 Gb video file upload to YouTube (Figure 36). Video upload throughput resembled prior upload speeds recorded on the commercial speed test server (speedtest.net).

Figure 36. Network Monitor Speed Test and Video Upload Capture



An nslookup, ping, and traceroute command was used to resolve the YouTube IP address (Figure 37) and display the complex routing involved. This information assisted in the attempt to determine the cause of the throughput reduction, but no definitive resolution was found. Multiple hops were observed and latency increased due to the extra routing involved when compared to the O3b Networks Vernon gateway test, which terminates after the signal arrives at the gateway. This is common when testing satellite performance, due to the removal of the commodity Internet or other routers that potentially hinder throughput performance.

Figure 37. Command Line Routing



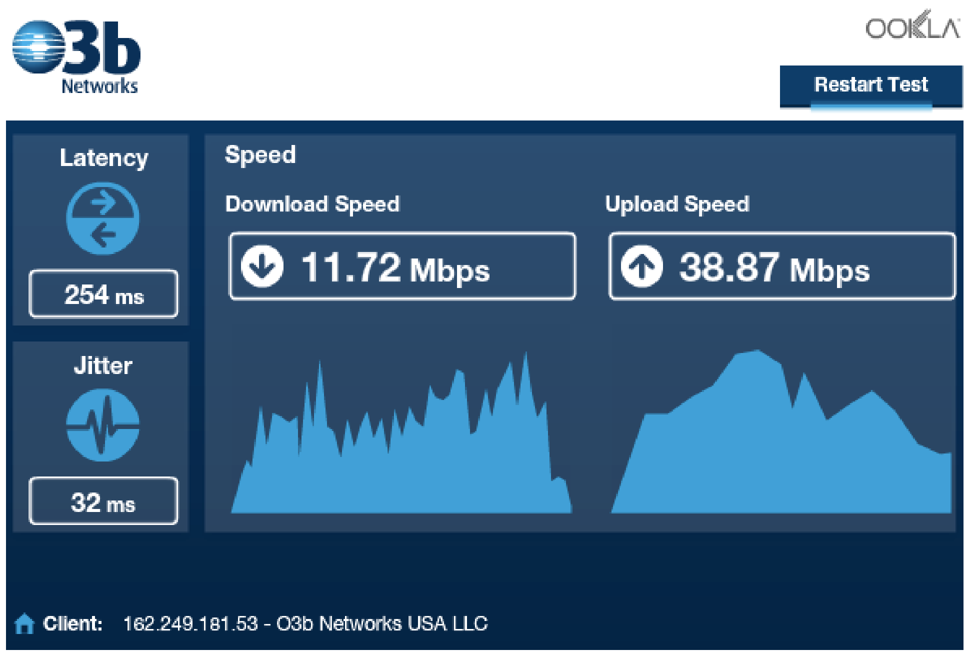
```
rcadams — bash — 110×57
Tabasco:~ rcadams$ nslookup www.youtube.com
Server:         192.168.1.1
Address:        192.168.1.1#53

Non-authoritative answer:
www.youtube.com canonical name = youtube-ui.l.google.com.
Name:   youtube-ui.l.google.com
Address: 216.58.218.142

Tabasco:~ rcadams$ ping 216.58.218.142
PING 216.58.218.142 (216.58.218.142): 56 data bytes
64 bytes from 216.58.218.142: icmp_seq=0 ttl=55 time=183.039 ms
64 bytes from 216.58.218.142: icmp_seq=1 ttl=55 time=183.234 ms
64 bytes from 216.58.218.142: icmp_seq=2 ttl=55 time=182.577 ms
64 bytes from 216.58.218.142: icmp_seq=3 ttl=55 time=183.176 ms
64 bytes from 216.58.218.142: icmp_seq=4 ttl=55 time=182.497 ms
64 bytes from 216.58.218.142: icmp_seq=5 ttl=55 time=182.334 ms
64 bytes from 216.58.218.142: icmp_seq=6 ttl=55 time=183.156 ms
64 bytes from 216.58.218.142: icmp_seq=7 ttl=55 time=182.678 ms
^C
--- 216.58.218.142 ping statistics ---
8 packets transmitted, 8 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 182.334/182.836/183.234/0.331 ms
Tabasco:~ rcadams$ traceroute 216.58.218.142
traceroute to 216.58.218.142 (216.58.218.142), 64 hops max, 52 byte packets
 1  192.168.1.1 (192.168.1.1)  3.226 ms  2.161 ms  2.042 ms
 2  otn1.usa-avl-003.vrn.o3bnetworks.net (162.249.181.50)  143.858 ms  142.327 ms  142.574 ms
 3  38.122.39.18 (38.122.39.18)  146.401 ms  146.514 ms  146.482 ms
 4  gi0-0-1-2.agr12.dfw03.atlas.cogentco.com (38.122.39.17)  146.831 ms  146.937 ms  147.030 ms
 5  te0-6-1-1.ccr22.dfw03.atlas.cogentco.com (154.54.7.205)  146.978 ms  149.216 ms
    te0-4-0-35.ccr21.dfw03.atlas.cogentco.com (154.54.7.181)  147.112 ms
 6  be2031.ccr21.dfw01.atlas.cogentco.com (154.54.7.45)  147.721 ms
    be2269.ccr21.dfw01.atlas.cogentco.com (154.54.7.41)  147.495 ms
    be2032.ccr22.dfw01.atlas.cogentco.com (154.54.6.53)  147.502 ms
 7  be2433.ccr22.mci01.atlas.cogentco.com (154.54.3.214)  156.609 ms
    be2432.ccr21.mci01.atlas.cogentco.com (154.54.3.134)  157.065 ms  156.962 ms
 8  be2157.ccr42.ord01.atlas.cogentco.com (154.54.6.118)  169.191 ms  169.124 ms
    be2156.ccr41.ord01.atlas.cogentco.com (154.54.6.86)  169.604 ms
 9  be2216.ccr41.ord03.atlas.cogentco.com (154.54.24.202)  169.885 ms
    be2217.ccr41.ord03.atlas.cogentco.com (154.54.24.206)  169.779 ms  168.944 ms
10  38.88.204.78 (38.88.204.78)  189.531 ms  189.620 ms  189.307 ms
11  209.85.254.120 (209.85.254.120)  181.311 ms
    209.85.143.154 (209.85.143.154)  180.661 ms
    209.85.254.128 (209.85.254.128)  181.463 ms
12  209.85.241.51 (209.85.241.51)  182.373 ms
    209.85.241.47 (209.85.241.47)  183.243 ms  182.897 ms
13  209.85.143.101 (209.85.143.101)  182.294 ms
    72.14.239.168 (72.14.239.168)  182.369 ms  181.698 ms
14  209.85.249.68 (209.85.249.68)  184.465 ms
    209.85.243.13 (209.85.243.13)  183.792 ms
    209.85.249.68 (209.85.249.68)  181.809 ms
15  66.249.95.199 (66.249.95.199)  182.228 ms
    72.14.237.220 (72.14.237.220)  182.396 ms
    66.249.95.199 (66.249.95.199)  182.025 ms
16  72.14.234.143 (72.14.234.143)  183.867 ms  184.455 ms  182.533 ms
17  dfw25s08-in-f14.1e100.net (216.58.218.142)  182.483 ms  184.178 ms  182.416 ms
Tabasco:~ rcadams$
```

Next, a speed test utilizing the NPS VPN indicated a reduction in throughput (Figure 38). Average download speeds revealed 11.45 Mbps and average upload speeds were 30.21 Mbps. This throughput reduction is likely due to the intrusion prevention system (IPS)/intrusion detection system (IDS) and firewall inspections on inbound traffic to the network. An additional traceroute to YouTube was conducted while connected to the NPS VPN to show the increase in latency experienced (Figure 39).

Figure 38. NPS VPN Speed Test



Last Result:
Download Speed: **11724** kbps (1465.5 KB/sec transfer rate)
Upload Speed: **38870** kbps (4858.8 KB/sec transfer rate)
Latency: **254** ms
Jitter: **32** ms
9/17/2015, 2:25:22 PM

Figure 39. NPS VPN Increased Latency

```
Name:    youtube-ui.l.google.com
Address: 74.125.239.32

Tabasco:~ rcadams$ traceroute 172.20.20.11
traceroute to 172.20.20.11 (172.20.20.11), 64 hops max, 52 byte packets
 1  lee.ern.nps.edu (172.20.20.11)  202.414 ms  239.373 ms  203.513 ms
 2  lee.ern.nps.edu (172.20.20.11)  203.187 ms  201.665 ms  205.277 ms
Tabasco:~ rcadams$
```

2. 4U Mini-XMS Server

a. Battery Tests

Testing the server's operation using six NiMH batteries within the 6-Pack enclosure resulted in 7.1 hours of continuous operation. Using six Li-ion batteries in the same enclosure resulted in 14.2 hours of continuous operation. "Operation" included typical workflows associated with ingest of live-streaming video, upload of video files, transcoding for content delivery and interaction with the ViaPlatz-XMS graphical user interface by four simultaneous users. This workload simulates potential use of this system in the field during HA/DR or community relation (COMREL) projects.

b. Memory Performance

Testing in our Digital Video Lab revealed a problem with the Intel S3500 SSD used for main system memory. The drives are advertised to have a maximum write speed of "up to" 380 mega-bytes per second (MBps). In independent tests conducted at Aspen Systems, speeds dropped below 200 MBps and were unable to keep up with the accumulated buffering of incoming video signals.

It was concluded that capturing directly from an HD camera, running HD video (1080p 30 fps) in 10-bit color, meant that the data rate far exceeded the capability of the disks to record it. Each time a recording was attempted, the system would run for approximately 45–60 frames (1.5–2 seconds), and then the frame counter would fail to increment. Upon review, the video only had a few seconds at most for each test.

The formula used for calculating constant bit-rate is:

*Uncompressed data rate = color depth * vertical resolution * horizontal resolution * refresh frequency*

Our evaluation of HD content required the following minimum read/write speed:

3 x 10-bit (10-bits per channel) * 1920 x 1080 * 30 = 444.946 MBps

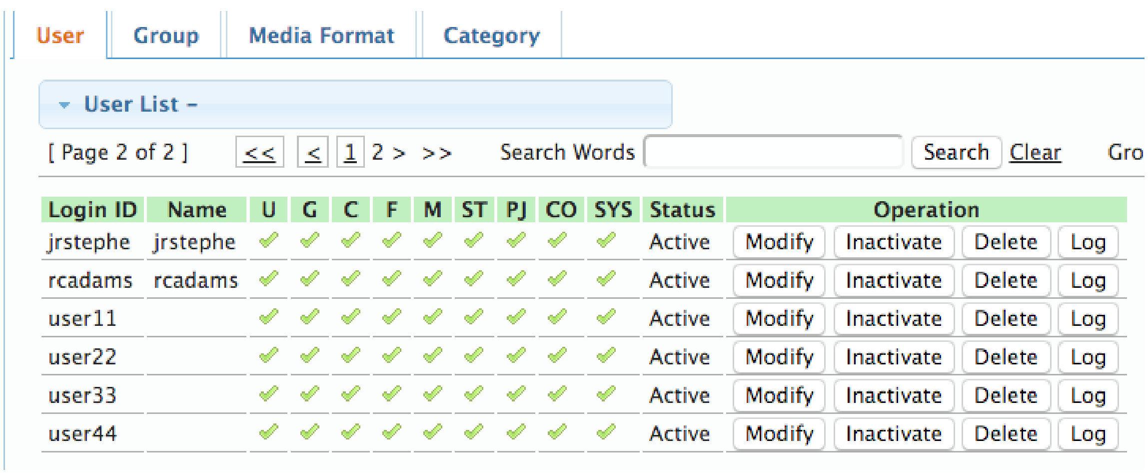
Extensive tests revealed that the Intel S3500 SSDs were inadequate for the project. The drives were returned to the vendor and Aspen Systems replaced the drives with Samsung PM863 SSDs which had a sequential write speed of 475 MBps (and read speed of 520 MBps). These SSDs were slightly larger capacity than the Intel drives as well.

The Mini-XMS was reconfigured by Aspen Systems with the new SSDs and returned to NPS. After a software update in August 2014, they tested successfully with HD and 4k video content.

c. *Media Ingestion Evaluation*

For our evaluation, four additional user accounts were created to stress the mini-xms server during the file-based media ingestion evaluation. Figure 40 shows the ViaPlatz users and associated privileges.

Figure 40. ViaPlatz Users and Account Privileges



Users uploaded various video content recorded at different resolutions simultaneously and files were stored on the SSD array awaiting future transcoding. Figure 41 shows media upload awaiting transcoding.

Figure 41. Video Content Transcoding Que

Materials in transcoding

Material Name	Format	Bitrate	Task Status	File exists?	Current Transcoding Status	Task ID
Exotics 3	flv	384Kbps	STARTED	True	Transcoding file [1/1] 79% Done (Wed Nov 4 05:21:21 2015)	1e66914c-f868-4e9a-a8ec-03fc79d5b3fd
Exotics 3	mp4	384Kbps	STARTED	True	Transcoding file [1/1] 79% Done (Wed Nov 4 05:21:21 2015)	2403b974-ae48-40b2-b817-9fb43a1d1bb6
Exotics 3	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	2ec19bd0-6e7a-4693-ba6a-8a1dca48e648
Exotics 3	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	8300f5d1-08d7-4730-b79b-f4d1edcb8453
Exotics 3	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	c4d11087-70ef-4d2e-bf46-d0bc27b1447f
Exotics 3	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	3e8be83f-6d73-4df1-a1e3-9d2cfe307dc0
Exotics 3	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	20d3d012-d468-4342-b9b1-f87ce451e773
Grandpa and Grandma 2	flv	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	60eefd07-ffbd-47ba-8b42-34220db5aa43
Grandpa and Grandma 2	mp4	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	f9b639b2-2926-4f7d-a012-89a00cf03f43
Grandpa and Grandma 2	flv	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	2ac8edb7-f7c0-46ec-8c9d-fa2bcaf351f4
Grandpa and Grandma 2	mp4	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	50bc91d8-b921-4c4d-b870-64b2112413e3
Grandpa and Grandma 2	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	7dc7b2af-4aea-4900-b4a5-86559931edec
Grandpa and Grandma 2	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	6fe9d2b3-6333-4d07-bbbe-76a8fa858a41
Grandpa and Grandma 2	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	2b844d15-cf22-4810-8921-fb0677b4e475
Grandpa and Grandma 2	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	64e477ce-123a-405b-8daf-7e34da94db82
Grandpa and Grandma 2	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	0c9c1c6e-79ae-49d1-9ee3-63b948f32c97
Grandpa and Grandma 2	mp4	for SceneEditor	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	d1203d01-cd05-490c-aedd-857b86de0dd8
Jack Eating 2	mp4	for SceneEditor	PENDING	False	Waiting to start (Wed Nov 4 03:16:46 2015)	9045b426-eb5a-4274-baf4-ebdc57f1f27f
Jack Eating 2	flv	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:46 2015)	06de6931-b632-4f41-bbc2-944e3eb4cf24
Jack Eating 2	mp4	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	26e1c911-9fc0-4a0b-a358-143df9481ba5
Jack Eating 2	flv	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	550784f0-0020-44da-8f5b-3e4e830293f3
Jack Eating 2	mp4	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	6c1edb59-98b1-451f-8e2b-9a7f60990cc1
Jack Eating 2	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	ca9abca9-35ca-40d6-8f19-2849f29624ae
Jack Eating 2	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	41b07a84-fa16-4835-bcb0-5da9ba958fc2
Jack Eating 2	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	b8518c3f-2bd6-497d-9022-357867c6957a
Jack Eating 2	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	96a4ec5c-289b-4155-9f51-ee6c26f8bacf
Jack Eating 2	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	f21acdcf-7f45-45fd-94b2-0267fb4fcf25

Streaming media ingestion was accomplished via 3G-SDI from our GY-HM750 JVC HD studio camera into the XMS portion of ViaPlatz. The studio camera was limited to 1080p HD content at 30 fps. Figure 42 shows our streaming media evaluation capturing ceiling fan movement.

Figure 42. Streaming Media Content Test

XMS	File Name	Header	Thumbnails	Operation
mini-xms	Expport.Test.mov	Duration: 19.019 sec, File Size: 369868459 Video: [prores] 1920 x 1080 @ 29.97 (Video: prores, yuv422p10le, 1920x1080, 155576 kb/s) No audio		Import as XMS File · Copy/Transcoding · Download · Full Size Samples · Delete

View Task Status

d. Transcoding Evaluation

Our portable video content server is capable of handling one 4k uncompressed video stream using our DeckLink 4K Extreme 12G video capture card. Both 4k and HD content were transcoded into FLV and MPEG4c containers for distribution at various bitrates (Figure 43). According to NTT, ingest codecs include H.264, H.263, MPEG4,

MPEG2, MPEG1, VC1, MJPEG, FLV, WMV2, WMV1, and various resolutions up to 4K60 fps (ViaPlatz, n.d.). Video compression for file based content was accomplished using the H.264 codec to provide the desired bitrate and real-time streaming utilized the MPEG2 TS and NTT video codecs. FLV and MPEG4 containers are pre-configured in ViaPlatz by NTT and are widely adopted digital video container formats, but the system is configurable for others if desired.

During transcoding operations for file based media, multiple 4K (3840 x 2160p30) and HD (1920x1080p60) video feeds were ingested simultaneously into the media server. The 4k footage utilized a .mov container used by a Panasonic Lumix DMC-GH4 digital single-lens reflex (DSLR) camera and HD content captured by a GoPro Hero 4 Silver used an .mp4 container.

Based on the desired delivery method, multiple bitrates and format combinations were selected, ranging from 150 Kbps to 11.1 Mbps. The variety of bitrates simulate potential content delivery constraints used by public affairs personnel. Real-time transcoding options were available via 3 gigabit serial data interface (3G-SDI), HDMI, composite, and component connections up to 4k and provided an extremely low latency (less than 1 frame) transport stream from ASIC-based transcoding services for uncompressed bitstreams. When going from an uncompressed bitstream to a compressed bitstream, a “chasing” transcoding stream occurs near instantaneously via software. This is possible due to operating on a high-speed multi-core processor server, otherwise it would be accomplished via “best effort.”

Multiple HD and UHD video files were uploaded simultaneously and placed in a queue awaiting transcoding (Figure 43). The ViaPlatz software transcodes two files at a time and the remaining files are placed into a queue awaiting processing. The system will allow content ingestion during transcoding by users, but scene editor transcoding must occur prior to collaboration between users. File transcoding occurs in the order the files were received by the system.

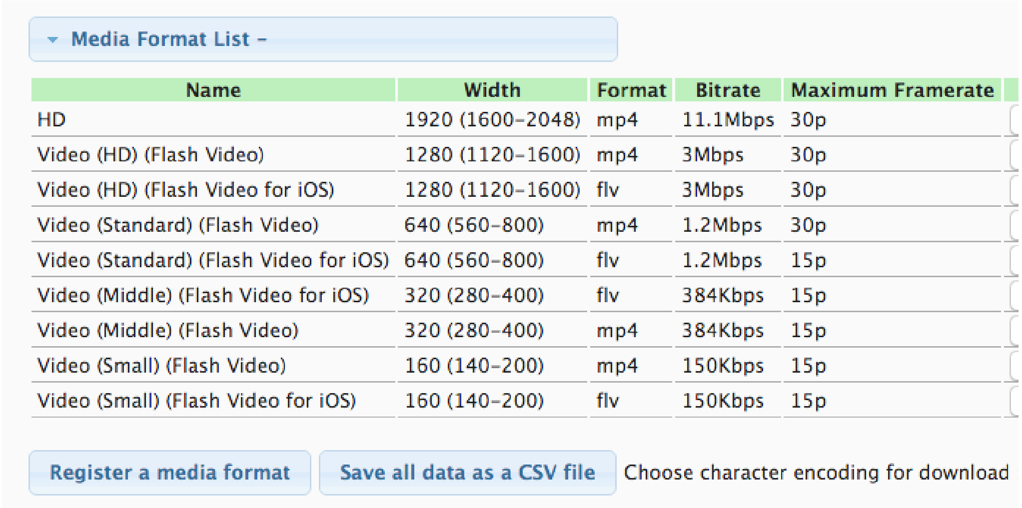
Figure 43. Transcoding Process

Materials in transcoding

Material Name	Format	Bitrate	Task Status	File exists?	Current Transcoding Status	Task ID
Exotics 3	flv	384Kbps	STARTED	True	Transcoding file [1/1] 79% Done (Wed Nov 4 05:21:21 2015)	1e66914c-f868-4e9a-a8ec-03fc79d5b3fd
Exotics 3	mp4	384Kbps	STARTED	True	Transcoding file [1/1] 79% Done (Wed Nov 4 05:21:21 2015)	2403b974-ae48-40b2-b817-9fb43a1d1bb6
Exotics 3	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	2ec19bd0-6e7a-4693-ba6a-8a1dca48e648
Exotics 3	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	8300f5d1-08d7-4730-b79b-f4d1edcb8453
Exotics 3	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	c4d11087-70ef-4d2e-bf46-d0bc27b1447f
Exotics 3	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	3e8be83f-6d73-4df1-a1e3-9d2cfe307dc0
Exotics 3	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	20d3d012-d468-4342-b9b1-f87ce451e773
Grandpa and Grandma 2	flv	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	60eefd07-ffbd-47ba-8b42-34220db5aa43
Grandpa and Grandma 2	mp4	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	f9b639b2-2926-4f7d-a012-89a00cf03f43
Grandpa and Grandma 2	flv	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	2ac8edb7-f7c0-46ec-8c9d-fa2bcaf351f4
Grandpa and Grandma 2	mp4	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	50bc91d8-b921-4c4d-b870-64b2112413e3
Grandpa and Grandma 2	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	7dc7b2af-4aea-4900-b4a5-86559931edec
Grandpa and Grandma 2	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	6fe9d2b3-6333-4d07-bbbe-76a8fa858a41
Grandpa and Grandma 2	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	2b844d15-cf22-4810-8921-fb0677b4e475
Grandpa and Grandma 2	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	64e477ce-123a-405b-8daf-7e34da94db82
Grandpa and Grandma 2	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:07:15 2015)	0c9c1c6e-79ae-49d1-9ee3-63b948f32c97
Grandpa and Grandma 2	mp4	for SceneEditor	PENDING	False	Waiting to start (Wed Nov 4 05:21:21 2015)	d1203d01-cd05-490c-aedd-857b86de0dd8
Jack Eating 2	mp4	for SceneEditor	PENDING	False	Waiting to start (Wed Nov 4 03:16:46 2015)	9045b426-eb5a-4274-baf4-ebdc57f1f27f
Jack Eating 2	flv	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:46 2015)	06de6931-b632-4f41-bbc2-944e3eb4cf24
Jack Eating 2	mp4	150Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	26e1c911-9fc0-4a0b-a358-143df9481ba5
Jack Eating 2	flv	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	550784f0-0020-44da-8f5b-3e4e830293f3
Jack Eating 2	mp4	384Kbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	6c1edb59-98b1-451f-8e2b-9a7f60990cc1
Jack Eating 2	flv	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	ca9abca9-35ca-40d6-8f19-2849f29624ae
Jack Eating 2	mp4	1.2Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	41b07a84-fa16-4835-bcb0-5da9ba958fc2
Jack Eating 2	flv	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	b8518c3f-2bd6-497d-9022-357867c6957a
Jack Eating 2	mp4	3Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	96a4ec5c-289b-4155-9f51-ee6c26f8bacf
Jack Eating 2	mp4	11.1Mbps	PENDING	False	Waiting to start (Wed Nov 4 03:16:47 2015)	f21acdcf-7f45-45fd-94b2-0267fb4fcf25

While there are many formats available for distribution, this thesis concentrated on widely accepted formats for content delivery used throughout the industry. Figure 44 shows content delivery options that were designed into the system by the NTT engineers. Input formats vary depending on the device used. Our system recognizes 3G-SDI, HDMI, component, composite, and IP based physical connections via 1Gb Ehternet. HD, 2k, and 4k uncompressed bitstreams can be ingested into the system and Quicktime containers, Apple ProRes files, MPEG-4, DPX, TIFF are supported by the current version of software.

Figure 44. Video Content Delivery Options



Media Format List –

Name	Width	Format	Bitrate	Maximum Framerate
HD	1920 (1600–2048)	mp4	11.1Mbps	30p
Video (HD) (Flash Video)	1280 (1120–1600)	mp4	3Mbps	30p
Video (HD) (Flash Video for iOS)	1280 (1120–1600)	flv	3Mbps	30p
Video (Standard) (Flash Video)	640 (560–800)	mp4	1.2Mbps	30p
Video (Standard) (Flash Video for iOS)	640 (560–800)	flv	1.2Mbps	15p
Video (Middle) (Flash Video for iOS)	320 (280–400)	flv	384Kbps	15p
Video (Middle) (Flash Video)	320 (280–400)	mp4	384Kbps	15p
Video (Small) (Flash Video)	160 (140–200)	mp4	150Kbps	15p
Video (Small) (Flash Video for iOS)	160 (140–200)	flv	150Kbps	15p

Register a media format

Save all data as a CSV file

Choose character encoding for download

C. SUMMARY

Evaluation of the O3b satellite system and our mobile video content server provided the quantitative information required to determine the effectiveness of the NPS field-deployable video cloud solution. O3b TFAAS satellite data was gathered over a two-day span and exceeded throughput expectations outlined in the engineering requirements. Low latency coupled with high-throughput performance makes the O3b TFAAS a viable solution for connectivity in deployed locations. Data from the mobile video content server evaluation was gathered locally and echoed the desire for a deployable mobile video content management capability. Creating multiple user accounts enabled U.S. to simulate a demanding environment for the content server and evaluate software stability. Li-ion battery power testing performance greatly exceeded the engineering requirements and will be the recommended battery type for employment.

V. SUMMARY AND CONCLUSION

A. RESEARCH SUMMARY AND RECOMMENDATIONS

The purpose of this thesis was to evaluate a new video collaboration system coupled with a portable satellite system to support deployed public affairs personnel. With pressure to meet public affairs demands, the ability to deliver content in various formats from remote locations and provide instant collaboration between users should make a significant impact, especially when delivering time-sensitive content. In highly developed regions, high speed Internet connectivity is usually easy to obtain, but the Navy operates in austere conditions where typically no Internet connectivity exists. Satellite Internet provides connectivity in these remote locations; however, with satellite resources in high demand, limited availability and partial bandwidth for use is always a concern. A MEO satellite solution like O3b Networks is capable of providing the throughput required to transmit UHD video from remote locations.

The O3b Networks .85m TFAAS satellite system was evaluated for use in conjunction with the mobile content collaboration server, and based on our findings, the system performance greatly exceeded the engineering requirements. The system provided sufficient throughput and latency issues are greatly reduced using a MEO satellite system when compared to a GEO satellite system. MEO satellites prove to be more efficient when operating in a TCP/IP environment and are a good choice when available. TFAAS satellite acquisition was accomplished in a timely manner, satellite connection was constant, and automatic handoffs between the terminals were seamless with no break in service. The total throughput of 541.51 Mbps is a vast improvement over any GEO satellite technology in use today, and is more than capable of handling UHD video content delivery. In addition, latency (138.25 ms) observed in the system was significantly lower when compared to GEO satellite systems, making it the best choice for implementation.

We utilized a mobile content collaboration server that allowed for UHD content ingestion, video collaboration between multiple users, and various popular content

delivery formats using compression techniques that allow for bit rate solutions for widest dissemination. The 4U mobile video content server requires SSDs with fast read/write speeds (in excess of 450 MBps minimum for HD content) and multi-core processors to support transcoding operations. Onboard ASIC services coupled with NTT ViaPlatz software transcode one 4k uncompressed bitstream with extremely low latency while still giving users the ability to record content. With a variety of media ingestion possibilities, our mobile video content server provides media collaboration capabilities and content delivery methods that support public affairs operations.

The mobile content collaboration server requires power from either an AC or DC source. Our evaluation of the server power source tested two different battery types for use in a deployed environment. While NiMH batteries exceeded the engineering requirements and powered the system for 7.1 hours, Li-ion battery performance proved even better for use with the system by supplying power for 14.2 hours. The Bren-Tronics portable enclosure proved effective to house the batteries while providing durability.

Our mobile video content server paired with the O3b TFAAS system will meet the requirements and capabilities that public affairs personnel need to accomplish their mission. We recommend the NPS field-deployable video cloud solution for media ingestion, video collaboration, and content delivery coupled with the O3b TFAAS satellite solution or equivalent for use within the U.S. Navy.

B. FUTURE RESEARCH

This thesis evaluated an approach to video collaboration and distribution using different resolutions up to 4k and provided a delivery method using a commercial SATCOM solution. Based on this research, certain follow-on studies, described below, are recommended.

1. Communication Security

This research did not address security issues in the testing and evaluation, but we recognize that communication security is important, especially in the tactical environment. While the commercial SATCOM industry does not typically include

security solutions with their products, several options are available for use. DOD requires the use of High Assurance Internet Protocol Encryption (HAIPE) devices to protect SATCOM communications and future research of these approved devices for use with the .85m TFASS system would prove beneficial.

2. Shipboard Server or Video Cloud System

This research evaluated a portable video cloud solution for use by USN public affairs personnel. While a portable solution is ideal for deployed personnel in the field, a permanent ship-board video server should be researched and evaluated for video-on-demand services (e.g., video training, movies on demand), potential long-term content management (until the end of deployment) with searchable content, and if utilized with a high-throughput SATCOM connection, a video cloud service for other entities to access content underway.

3. 4G LTE and Wi-Fi Capability

A recent evaluation took place on USS *Fort Worth* (LCS-3) where O3b Networks provided high-throughput SATCOM connectivity to Oceus Networks for 4G long term evolution (LTE) service onboard LCS-3 and to surrounding vessels within the coverage area. While this was just a proof-of-concept evaluation, results show that utilizing a high-throughput SATCOM system, like O3b Networks, can provide the required throughput HD video demands, as well as 4G LTE SATCOM connectivity. This research focused on a video content collaboration server with a satellite Internet connection and did not have access to 4G LTE technology. Future research to provide cellular or Wi-Fi capabilities while using the content server could prove to be beneficial in remote locations for public affairs personnel.

4. Scaled Throughput

Our evaluation of the O3b Networks .85m meter solution greatly exceeded the research requirements. While the throughput observed was skewed more to download content, having the ability to skew towards upload would prove beneficial when

delivering content. Future research should be conducted to find the optimal throughput balance between download/upload for UHD video content delivery.

C. CONCLUSION

There exists a need for mobile video collaboration within the Navy and other DOD agencies that utilize a high-throughput SATCOM solution for connectivity. This research focused on the USN public affairs requirement for this capability, but it is apparent that the desire expands to all branches and entities within the DOD. The ability to manage UHD video content from deployed locations and deliver it to the appropriate destination rapidly has not been available until now. This research delivers a capability to public affairs personnel that enables the ability to meet high levels of content demand. Budgetary adjustments should be considered to acquire this capability for widest dissemination within the DOD. The Navy has established the need for more video services and distribution from anywhere in the world and within the fleet. Based on the evaluations conducted, utilization of the NPS Field-Deployable Video Cloud Solution can fill the void that plagues content delivery in a deployed environment.

APPENDIX A. GLOSSARY

Source: Poynton, C. (2012). *Digital video and HD: Algorithms and Interfaces*. Elsevier, 581–668.

2k	Relating to image representations having 2048 image columns (samples per picture width), such as 2048x1080; particularly the system for digital cinema devised by the DCI and standardized by SMPTE.
3G-SDI	A serial digital interface (SDI) having a data rate of either 2.97 Gb/s, commonly used to transport 1080p30, 4:4:4 video and also capable of 1080p60, 4:2:2.
4k	Relating to image formats having 4096 image columns (samples per picture width), such as 4096x2160; particularly the system for digital cinema devised by the DCI and standardized by SMPTE. 4k imagery is normally represented in a color space that mimics cinema.
4:0:0	Greyscale video (sometimes confusingly called monochrome)
4:1:1	Chroma subsampling wherein CB and CR components are horizontally subsampled by a factor of 4 with respect to luma, and not subsampled vertically.
4:2:2	Chroma subsampling wherein each CB and CR component is horizontally subsampled by a factor of 2 with respect to luma, and not subsampled vertically.
4:4:4	Component digital video, typically SDTV, where R'G'B' or Y'CBCR components are conveyed with equal data rate.
4:4:4:4	A 4:4:4 system, as above, augmented by a transparency or alpha channel sampled at the same rate as the luma component.
16:9	The standard aspect ratio of HD.
23.976 Hz	A common frame rate for cinema production involving interface to SD or HD video.
29.94 Hz	The usual frame rate for interlaced video production in North America and Japan.

360p	A progressive video standard having image structure of 480x360; suitable for square-sampled SD content oat 16:9 aspect ratio.
480i, 480i29.97	An interlaced scanning standard used primarily in North America and the Far East, having 525 total lines per frame, approximately 480 picture lines (usually in an image structure of 720×480), and 29.97 frames per second. A raster notation such as 480i29.97 does not specify color coding; color in 480i29.97 systems is conveyed in the studio using R'G'B', Y'CBCR, or Y'PBPR components, and encoded for transmission using composite NTSC.
540p	A progressive image format having an image structure of 960x540.
720p	A progressive image format for HD, having an image structure of 1280x720, and any of several frame rates including 23.976, 24, 29.97, 30, 59.94, of 60 Hz.
1080i	An interlaced image format for HD having an image structure of 1920x1080 and a frame rate of 29.97 Hz or 30.00 Hz.
1080p	A progressive image format for HD, having an image structure of 1920x1080, and any of several frame rates including 23.976, 24, 29.97, 30, 59.94, of 60 Hz.
ACES	Academy Color Encoding Specification.
Aspect Ratio	The ratio of the width of an image to its height.
ATSC	Advanced Television Systems Committee: A U.S.-based organization that standardizes and promotes digital SDTV and HDTV broadcasting. ATSC advocates MPEG-2 video compression and Dolby Digital (AC-3) audio compression, supplemented by ATSC terrestrial broadcasting transmission standards.
AVCHD	A consumer HD system for 720p, 1080i, and 1080p24, adapted for professional use, typically using 12cm DVD-R media, SDHC flash memory cards, or hard disk drive recording, using long GoP H. 264 video coding, Dolby Digital audio coding, and having a bit rate between 6 Mb/s and 18 Mb/s.
Bayer pattern	The mosaic pattern named for Kodak researcher Bryce E Bayer, comprising a 2x2 arrangement of photosites or pixel components representing red, gree, green, and blue.

Bit error ratio	The probability that recording or transmission in an error-prone medium corrupts any single bit transmitted or recorded.
Bit error rate	The rate of occurrence of erroneous bits.
bpp	Bits Per Pixel. The number of bits allocated to each pixel; in an uncompressed representation, the “bit depth” of the pixel.
CMOS image sensor	An image sensor constructed using CMOS technology. Each photosite has a photodiode that converts incident photons to electrons, and a small number of transistors (typically 3 or 4) that amplify and gate the corresponding voltage to an amplifier and/or analog-to-digital converter for subsequent transmission off-chip.
CODEC	Coder/decoder: Hardware circuitry, firmware, software, or equipment to encode or decode data between two formats (perhaps analog and digital, or between two digital formats), often including signal compression or decompression.
Concatenated	In compression, two or more compression systems in series. Also known as tandem codecs.
Contrast ratio	The ratio between specified light and dark, luminances, typically the luminance associated with the peak white or reference white of a display system and the luminance associated with reference black.
Data rate	Information rate of digital transmission, ikn bits per second (b/s) or bytes per second (B/s).
Decoding	1. Generally, converting one or more coded signals into uncompressed form, reversing a previous encoding operation that was applied to reduce data rate for transmission or recording. 2. In traditional video usage, taking composite video, such as NTSC or PAL, performing luma/chroma separation and chroma demodulation, and producing component video output such as Y’CBCR or R’G’B’. 3. In modern video usage, taking coded picture information (such as a JPEG, M-JPEG, or MPEG compressed bitstream) and recovering uncompressed picture data.
Downconversion	In video, conversion to a scanning standard, usually at the same frame rate, having substantially lower pixel count (e.g.,, HDTV to SDTV).

Dual-link HD-SDI	Dual-link high-definition serial digital interface: A SMPTE standard interface using a pair of HD-SDI links to transmit 4:4:4:4 HD.
Encoding	1. Generally, the process of converting one or more signals into a more complex representation, with the goal of reducing data rate for transmission or recording. 2. In traditional video usage, the process of taking component video input (e.g.,, Y'CBCR or R'G'B'), performing chroma modulation and luma/chroma summation, and producing composite video (e.g.,, NTSC or PAL). 3. In modern video usage, the processing of uncompressed image data to produce a compressed bitstream (such as in JPEG, M-JPEG, or MPEG compression).
Frame	The time interval of a video signal that contains all of the elements of one picture, complete with all of the associated preceding sync elements. In analog, measured between 0V instants; in digital, measured between the EAVs preceding line In an interlaced system, a frame comprises two fields, first and second, which normally exhibit temporal coherence; each field contains half the scanning lines and half the picture lines of the frame.
Gamut	Generally, the largest possible set of colors of a particular device or circumstance. 1. Of a display device, the set of colors that can be produced in a particular viewing condition. 2. Of a color interchange space, the set of colors that can be represented across all permitted codeword combinations – for example, RGB video signals each ranging from reference black to peak white – when displayed as intended and analyzed colorimetrically in a particular viewing condition. 3. Of a camera whose output is characterized colorimetrically, the set of colors represented across all possible output codeword combinations, displayed as intended and analyzed colorimetrically in a particular viewing condition.
H.264	Formally, ITU-T H.264, also published as ISO/IEC 14496-10 and known as MPE-4 Part 10: A standard, jointly developed by ISO, IEC, and ITU-T, for the lossy compression of digital motion images and associated audio. The H.264 algorithm is based upon the basic principles of MPEG-2, but has many additional features that offer improved bit rate for the same performance (at the

expense of additional encoder and/or decoder complexity). H.264 is sometimes lossely referred to as MPEG-4 however, that term does not uniquely identify H.264 because MPEG-4 Part 2 defines unrelated (SP/ASP and SStP) codecs.

HD	High-definition (video): There is no official definition; generally, a video system having aspect ration of 16:9, frame rate of 23.976 Hz or higher, image data comprising 729 Kpixes (about 3/4 –million pixels) or more, and at least two channels of digital audio. Commonly either 720p or 1080i or 1080p. Appending the letters TV (HDTV) implies entertainment programming.
HD-SDI	High-definition serial digital interface: A SMPTE-standard interface, having a data rate of about 1.485 Gb/s, for uncompressed studio-quality HDTV.
Interlace	A scanning standard in which alternate raster lines of a frame are displaced vertically by half the scan-line pitch and displaced temporally by half the frame time to form a first field and a second field. Examples are 480i29.97 (525/59.94), 576i25 (625/50), and 1080i30 (1125/60). Systems with high-order interlace have been proposed but none has been deployed, so modern usage of the term interlace implies 2:1 interlace
Interleaved	A method of storing pixels whereby all components of a pixel occupy adjacent storage locations. A 3x2 image matrix of 8-bit, RGB data could be stored as bytes in the order RGB RGB RGB RGB RGB RGB. Also known as band-interleaved by pixel (BIP), chunky, packed pixel , or pixel interleaved.
ITU-R	International Telecommunications Union, Radiocommunications Sector; successor to the Comité Consultatif Internationale des Radiocommunications (International Radio Consultative Committee, CCIR): A treaty organization that obtains international agreement on standards for radio and television broadcasting. The ITU-R BT series of Recommendations and Reports deals with television. Although studio standards do not involve radio transmission in a strict sense, they are used in the international exchange of programs, so they are under the jurisdiction of ITU-R.
MP4(.mp4)	A container (file) format used in MPEG-4 Parts 1 and 14 (not Part 10/AVC) that is based upon the container format used in Apple's QuickTime system.

MPEG	Moving (not Motion!) Picture Experts Group: A standards committee, jointly constituted by ISO and IEC, that has developed standards for the lossy compression of digital motion images. The MPEG algorithms exploit the temporal coherence found in motion image sequences. The MPEG-2 standard (see below) is of interest to digital video and HDTV. Its predecessor, now denoted MPEG-1, offers VHS-quality. Other emergent MPEG standards, such as MPEG-4, MPEG-7, and MPEG-21, are for applications other than broadcast television.
MPEG-1	A standard, adopted by MPEG (see above), formally denoted ISO/IEC 11172, optimized for data rates of about 1.5 Mb/s and having approximately VHS quality.
MPEG-2	A standard, adopted by MPEG, co-published as ISO/IEC 13818 and ITU-T standard Rec. H.262, optimized for SD and HD at data rates of 4 Mb/s and higher.
MPEG-4	A set of standards promulgated by ISO and ITU-T MPEG; however, as commonly used, MPEG-4 is an ambiguous term: 1.MPEG-4 Part 2, formally known as ISO/IEC 14496-2 (Part 2), and informally known as SP/ASP; intended for low bit rate applications such as mobile and handheld broadcasting, but largely superseded in commercial application by H.264. 2. MPEG-4 Part 10, formally known as ISO/IEC 14496-10 (Part 10) defines a video compression scheme used for broadcast. To avoid confusion with MPEG-4 part 2 (SP/ASP), MPEG-4 Part 10 is better denoted by its ITU-T designation, H.264.
MPEG-4 Part 2 ASP	Formally, ISO/IEC 14496-2 (Part 2); A standard for video compression intended for low bit rate applications such as mobile and handheld broadcasting' it has been largely superseded commercially by H.264.
Nonlinear	Storage or processing of audio or video where the arrangement of data on the media is not in direct correspondence to the timeline. Magnetic tape is sometimes referred to as "linear" media' hard drive media is sometimes called "nonlinear."
NTSC	National Television System Committee

1. The group, now referred to as NTSC-][, that in 1941 standardized 525-line, 60.00 Hz field rate, interlaced monochrome television in the United States.

2. The group, formally referred to as NTSC-][ ][, that in 1953 standardized 525-line, 59.94 Hz field rate, interlaced color television in the United States. NTSC-][][introduced the composite video technique.

3. A method of composite video encoding based on quadrature modulation of I and Q (or U and V) color difference components onto a color subcarrier, then summing the resulting chroma signal with luma. Used only with 480i scanning, with a subcarrier frequency nominally 455⁄2 times the horizontal line rate (i.e.,, a subcarrier frequency of about 3.579545 MHz).

4. Often incorrectly used to denote 480i29.97 (525/59.94) scanning.

Pixel — Picture element. Unfortunately, a deeply ambiguous term;

1. Historically, in greyscale digital imaging in general, and greyscale (monochrome) video in particular, the quantized sample value specific to a single spatial sampling site in an image.

2. Historically, in color digital imaging in general and color video in particular, and in modern systems that accomplish color separation or recombination using optical superposition, as set of three spatially coincident color component samples' perhaps augmented by spatially coincident data such as opacity data. Even in its historical interpretation, the term pixel is ambiguous when chroma subsampling is involved.

3. In the terminology of digital still cameras and by extension, in mosaic-sensor based digital cinema cameras – any single color component sample.

Progressive — A scanning standard in which spatially adjacent picture lines are associated with consecutive periodic (or identical) instants in time. Examples are 1080p24 and 720p60. Distinguished from Interlace.

ProRes — A family of proprietary intraframe codecs developed by Apple, compressing 10-bit video to data rates between about 82 Mb/s and 264 Mb/s.

QuickTime	Apple’s trademark identifying a system for encoding, recording, decoding and playing back realtime media on computers.
Raw	Image data encoding wherein no picture rendering and no chroma subsampling has taken place. Usually, image data is in scene-referred, linear-light form (though some systems use nonlinear conversion functions); usually, no compression has been applied (though some systems use wavelet or other compression schemes).
Rec 709	Formally, ITU-R Recommendation BT.709: The international standard for HDTV studio signals. Chromaticity and transfer function parameters of Rec. 709 have been introduced into modern studio standards for 480i and 576i. Rec. 709 specifies this luma equation (whose coefficients are unfortunately different from the Rec. 601 coefficients)
RGB	1. Strictly, red, green, and blue tristimulus components (linearlight). The precise color interpretation of RGB values depends on the chromaticity coordinates of the primaries and the chromaticity coordinates of reference white. The FCC 1953 NTSC standard (obsolete), SMPTE RP 145, EBU Tech. 3213, and Rec. 709 all specify different primary chromaticities. 2. Loosely, red, green, and blue nonlinear primary components, properly denoted R’G’B’
SD	Standard definition (video). There is no official definition, but generally, a video system having frame rate 23.976 Hz or greater whose digital image comprises fewer than about ¾ million pixels. The most widely deployed SD studio and broadcasting systems are 480i and 576i.
SMPTE	Society of Motion Picture and Television Engineers: A professional society that is also an ANSI-accredited standards-writing organization.
Transcoding	1. Traditionally, converting a video signal having one colorencoding method into a signal having a different color-encoding method, without altering the scanning standard; for example, 576i PAL to 576i SECAM.

	2. In compressed digital video distribution, various methods of recoding a compressed bitstream, or decompressing then recompressing.
Ultra-HDTV	Ultra-High Definition Television (UHD). Experimental video systems with a 7680x4320 image structure (frame rate undecided) and higher.
Uncompressed	In video, signal recording or transmission without using JPEG or MPEG techniques. (Chroma subsampling effects lossy compression with a ratio of about 1.5:1 or 2:1; however, the term compression in video is reserved for JPEG, M-JPEG, or MPEG techniques.)
VP8	An open-source video compression system, originally designed and implemented by On2' part of WebM.
WebM	An open-source project sponsored by Google, or the associated video/audio files, based upon the Matroska container format, Vorbis audio compression and VP8 video compression.

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APPENDIX B. AVL .85M TERMINAL BILL OF MATERIAL

Source: J. Shaw, personal communication, October 29, 2015.

.85m AVL Integrated Transportable Terminal with ViaSat MeoLink Modem with 20W BUC

Site Equipment Summary

Item	Description	Quantity
1	1 - .85CM Dual Transportable Terminal with 2 tracking antennas Model Number O3bD85	1
2	AVL mounting bracket for 20-Watt CPI O3bD85-CP20-AL	1
3	20-WATT CPI (Dual)	2
4	Norsat Ka Band LNBs (Dual)	2
5	12 port Ehternet Internet Interface Panel	1
6	DC distro panel	1
7	Shelf and splitters	1
8	RF interface Panel	1
9	AVL CPI/ViaSAT IFL	1

Sub-Total DUAL AVL .85M with 20W BUC, LNB, Modem and Router Equipment

AVL Integrated Kit 1 - Power Unit

Item	Description	Quantity
10	PELICAN CASE DE2121-02/30/02 10 ru rack case w/casters/shelves	1
11	AC/DC Converter 3600W MAJORPOWER MTS48/75AT-2U	1
12	30A Breaker, MAJORPOWER ST-B30A	1
13	EMERSON 3KVA UPS, 2RU, 120V - Part Number GXT4-3000RT 120 // Model Number GSTX 3000VA	1
14	PDU, 8 OUTLET, 120V // SERVER TECHNOLOGY INC C2-8H1A413	1
15	TEMP & HUMIDITY SENSOR // SERVER TECHNOLOGY INC // MODEL # 338229 (part of 14)	1
16	AYEKA TRACKING RECEIVER (Provided as part of the antenna terminal)	1
17	JUNIPER ETHERNET SWITCH PART 3 EX2200 / MODEL EX2200	1
18	EMERSON RMTKIT 18-32 RACK MOUNT KIT	1

Sub-Total for Power Unit Transportable Case System:

AVL Integrated Kit 2 - Modem & Router Unit

Item	Description	Quantity
19	PELICAN CASE DE2121-02/30/02 10 ru rack case w/casters/shelves	1
20	30A Breaker, MAJORPOWER ST-B30A	1
21	EMERSON IS-WEBCARD (ETHERNET CARD)	1
22	EMERSON RMTKIT 18-32 RACK MOUNT KIT	1
23	VIASAT MEOLINK MODEM	1
24	JUNIPER ROUTER ACX-1100	1
25	OPENCEAR ACM554-5-G-1 (OUT OF BAND ACCESS)	0
26	PDU, 8 OUTLET, 120V // SERVER TECHNOLOGY INC C2-8H1A413	1
27	TEMP & HUMIDITY SENSOR // SERVER TECHNOLOGY INC // MODEL # 338229	1
28	Cooling Fan for the rack	4

Sub-Total forModem & Router Transportable Case System:

Accessory Equipment

Item	Description	Quantity
29	PELICAN CR3126-15CF Cases	3

Gateway equipment Sub Total:

Gateway Equipment

Item	Description	Quantity
30	1 X Viasat High Data Rate modem	1

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